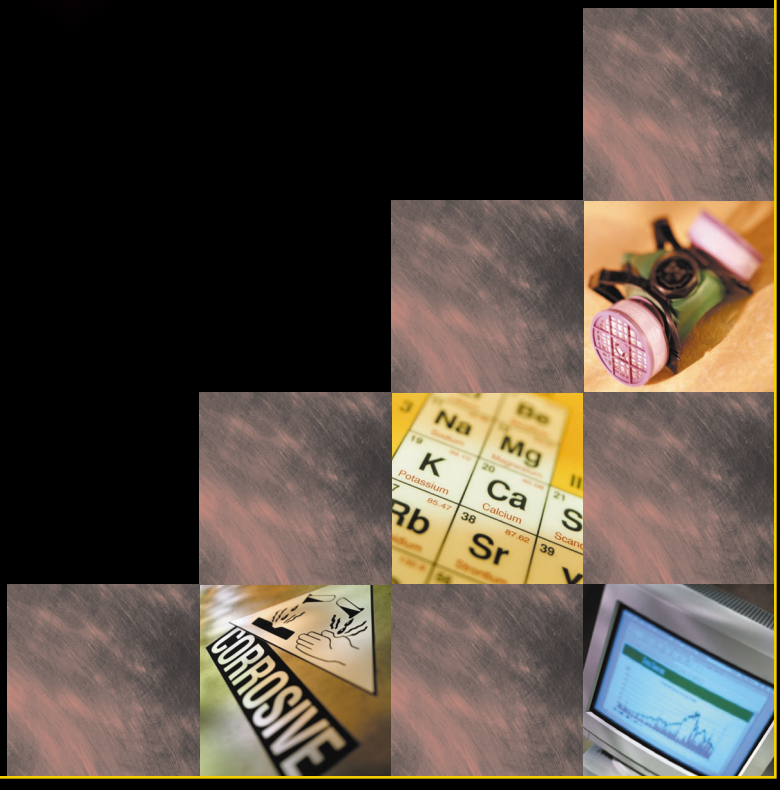
National Safety Council®

Fundamentals of Industrial Hygiene

5th Edition

Barbara A. Plog

Patricia J. Quinlan



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NATIONAL SAFETY COUNCIL MISSION STATEMENT

The mission of the National Safety Council is to educate and influence society to adopt safety, health, and environmental policies, practices, and procedures that prevent and mitigate human suffering and economic losses arising from preventable causes.

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Although the information and recommendations contained in this publication have been compiled from sources believed to be reliable, the National Safety Council makes no guarantee as to, and assumes no responsibility for, the correctness, sufficiency, or completeness of such information or recommendations. Other or additional safety measures may be required under particular circumstances.

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Foreword

The National Safety Council was chartered on the belief that information and planning are the keys to safety. For those beginning their careers or experienced safety and health professionals, *Fundamentals of Industrial Hygiene* continues to be the acclaimed standard of information for occupational and industrial hygiene professionals.

I encourage all employers, as well as safety and health professionals, to share the Council's commitment to preventing injury and illness and protecting people from hazards in the workplace. Fulfilling this commitment requires accurate, up-to-date information—the kind of comprehensive and current information contained in the fifth edition of the National Safety Council's *Fundamentals of Industrial Hygiene*. Written and edited by prominent industrial hygienists, occupational safety professionals and noted physicians, *Fundamentals of Industrial Hygiene* provides a useful guide to assist the reader, regardless of his or her knowledge base, to recognize, evaluate and control hazards in any type of workplace.

Throughout my own career, I have often referred to the most current edition of *Fundamentals of Industrial Hygiene* for valuable guidance. While at the Occupational Safety and Health Administration, I used earlier editions of *Fundamentals* to obtain in-depth knowledge and insight related to specific occupational environments, processes and procedures. Today, the book remains an indispensable tool to me and to National Safety Council staff, volunteers, members, chapters and affiliates in designing safety and health programs that are grounded in current scientific knowledge and real-life experience.

Whether establishing priorities, collecting and analyzing data, developing procedures to mitigate loss and suffering, or as a simple reference tool, *Fundamentals of Industrial Hygiene* assists every reader in the establishment of safety and health programs that are the foundation of our mission—preventing injury and illness, wherever they may occur.

Alan C. McMillan
President, National Safety Council

Preface

The fifth edition of *Fundamentals of Industrial Hygiene* comes at a time of continuing congressional activity that seeks to regulate how the federal Occupational Safety and Health Administration (OSHA) promulgates and enforces standards for health and safety in U.S. workplaces.

The words of then-OSHA head Joseph Dear to the American Industrial Hygiene Conference in Kansas City, Missouri, on May 24, 1995, still hold true, that OSHA strives to "guarantee that each worker who leaves for work in the morning arrives home safely each night." (*The Synergist*, American Industrial Hygiene Association, Volume 6, Number 6–7, p. 10, June/July, 1995.)

It is also clear the fundamental principles of industrial hygiene deserve more emphasis than at any time before.

This edition of *Fundamentals of Industrial Hygiene* presents original new chapters on Particulates (Chapter 8), Dilution Venilation of Industrial Workplaces (Chapter 20), Respiratory Protection (Chapter 22), The Occupational Medicine Physician (Chapter 25), and The Occupational Health Nurse (Chapter 26). All other chapters have been extensively updated and revised.

The primary purpose of this book is to provide a reference for those who have either an interest in or a direct responsibility for the recognition, evaluation, and control of occupational health hazards. Thus, it is intended to be of use to industrial hygienists, industrial hygiene students, physicians, nurses, safety personnel from labor and industry, labor organizations, public service groups, government agencies, and manufacturers. Others who may find this reference helpful include consultants, architects, lawyers, and allied professional personnel who work with those engaged in business, industry, and agriculture. It is hoped that this book will be of use to those responsible for planning and carrying out programs to minimize occupational health hazards.

An understanding of the fundamentals of industrial hygiene is very important to anyone involved in environmental, community, or occupational health. This manual should be of help in defining the magnitude and extent of an industrial hygiene problem; it should help the reader decide when expert help is needed.

Fundamentals of Industrial Hygiene is also intended to be used either as a self-instructional text or as a text for an industrial hygiene fundamentals course, such as the ones offered by the National Safety Council, various colleges and universities, and professional organizations.

The increase in the number and complexity of substances found in the workplace—substances that may spill over into the community environment—makes

imperative the dissemination, as efficiently and conveniently as possible, of certain basic information relating to occupational health hazards and resultant occupational diseases.

The book is organized into seven parts; each can stand alone as a reference source. For that reason, we have permitted a certain amount of redundancy.

Part One introduces the subject areas to be covered, in an overview of the fundamentals of industrial hygiene.

Part Two includes chapters on the fundamental aspects of the anatomy, physiology, hazards, and pathology of the lungs, skin, ears, and eyes. This background lays the groundwork for understanding how these organ systems interrelate and function.

Part Three is concerned with the recognition of specific environmental factors or stresses. The chemical substances, physical agents, and biological and ergonomic hazards present in the workplace are covered. The basic concepts of industrial toxicology are also presented in this section. Anticipation of these hazards is the desired result.

Part Four describes methods and techniques of evaluating the hazard. Included is one of the more important aspects of an industrial hygiene program: the methods used to evaluate the extent of exposure to harmful chemical and physical agents. Basic information is given on the various types of instruments available to measure these stresses and on how to use the instruments properly to obtain valid measurements.

Part Five deals with the control of the environmental hazards. Although industrial hygiene problems vary, the basic principles of health hazard control, problem-solving techniques, and the examples of engineering control measures given here are general enough to have wide application. To augment the basics, specific information is covered in the chapters on industrial ventilation.

Part Six is directed specifically to people responsible for conducting and organizing occupational health and safety programs. The fundamental concepts of the roles of the industrial hygienist, the occupational health nurse, the safety professional, and the occupational medicine physician in implementing a successful program are discussed in detail. Particular attention is paid to a discussion of the practice of industrial hygiene in the public and private sectors and to a description of the professional certification of industrial hygienists.

Part Seven contains up-to-date information on government regulations and their impact on the practice of industrial hygiene.

Appendix A provides additional resources. One of the most difficult parts of getting any project started is finding sources of help and information. For this reason, we have included a completely updated and comprehensive annotated bibliography and a listing of professional and service organizations, government agencies, and other resources.

Other appendixes include the ACGIH Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®), a review of mathematics, instructions on conversion of units, and a glossary of terms used in industrial hygiene, occupational health, and pollution control. An extensive index is included to assist the reader in locating information in this text.

We would like to gratefully acknowledge the work of the contributors to previous editions of the *Fundamentals of Industrial Hygiene*.

First Edition

1—Fundamental Concepts of Industrial Hygiene—Julian B. Olishifski, PE
2—Solvents and Health in the Occupational Environment— Donald R. McFee, ScD3—Pneumoconiosis-Producing Dusts—Fred Cook, MS
4—Industrial Dermatitis—Charles W. Wyman, BS
5—Industrial Noise—Herbert T. Walworth, MS

6—Basic Concepts of Ionizing Radiation Safety—E. L. Alpaugh, PE
7—Nonionizing Radiation: Lasers, Microwaves, Light—Julian B. Olishifski, PE
8—Effects of Temperature Extremes—E. L. Alpaugh, PE
9—Ergonomics Stresses: Physical and Mental—Julian B. Olishifski, PE
10—Evaluating the Hazard—J. B. Olishifski, PE
11—Toxicology—J. B. Olishifski, PE
12—General Methods of Control—J. B. Olishifski, PE
13—Respiratory Protective Equipment—A. M. Lundin, BS
14—Industrial Ventilation—W. G. Hazard, AM
15—General Ventilation and Special Operations—W. G. Hazard, AM
20—Setting Up an Industrial Hygiene Program—Julian B. Olishifski, PE
21—Sources of Information on Industrial Hygiene—Julian B. Olishifski, PE

Second Edition
1—Fundamental Concepts—Julian B. Olishifski, PE
2—The Lungs—Julian B. Olishifski, PE
3—The Skin—Julian B. Olishifski, PE
4—The Ear—Julian B. Olishifski, PE
5—The Eyes—Julian B. Olishifski, PE
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7—Particulates— Edwin L. Alpaugh, PE
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9—Industrial Noise—Julian B. Olishifski, PE
10—Ionizing Radiation—C. Lyle Cheever, MS, MBA
11—Nonionizing Radiation—Edward J. Largent and Julian B. Olishifski, PE
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15—Industrial Toxicology—Ralph G. Smith and Julian B. Olishifski, PE
16—Evaluation— Edward R. Hermann, CE, PhD, PE, CIH and Jack E. Peterson, PhD, PE, CIH
17—Methods of Evaluation—Julian B. Olishifski, PE
18—Air-Sampling Instruments—Julian B. Olishifski, PE
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28—The Occupational Health Nurse—Jeanette M. Cornyn
29—Industrial Hygiene Program—Edward J. Largent and Julian B. Olishifski, PE
30—Sources of Information—Julian B. Olishifski, PE and Robert Pedroza

Third Edition
1—Overview of Industrial Hygiene—Barbara Plog, MPH, CIH, CSP
2—The Lungs—George S. Benjamin, MD, FACS
3—The Skin—James S. Taylor, MD
4—The Ears—George S. Benjamin, MD, FACS
5—The Eyes—George S. Benjamin, MD, FACS
6—Solvents—Donald R. McFee, ScD, CIH, PE, CSP; Peter Zavon, CIH
7—Particulates—Theodore J. Hogan, PhD, CIH

8—Industrial Dermatoses—James S. Taylor, MD
9—Industrial Noise—John J. Standard, MS, MPH, CIH, CSP
10—Ionizing Radiation—C. Lyle Cheever, MS, MBA
11—Nonionizing Radiation—Larry E. Anderson, PhD
12—Temperature Extremes—Theodore J. Hogan, PhD, CIH
13—Ergonomics—Karl H. E. Kroemer, PhD
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17—Methods of Evaluation—Julian B. Olishifski, MS, PE, CSP
18—Air-Sampling Instruments—Maureen A. Kerwin (now Maureen A. Huey), MPH
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21—Industrial Ventilation—D. Jeff Burton, PE, CIH
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30—Governmental Regulations—M. Chain Robbins, BS, MPH, CSP, PE
31—Occupational Safety and Health: The Federal Regulatory Program—A History—Benjamin W. Mintz

Fourth Edition
1—Overview of Industrial Hygiene—Barbara A. Plog, MPH, CIH, CSP
2—The Lungs—George S. Benjamin, MD, FACS
3—The Skin and Occupational Dermatoses—James S. Taylor, MD
4—The Ears—George S. Benjamin, MD, FACS, and Barry J. Benjamin, MD, FACS
5—The Eyes—George S. Benjamin, MD, FACS
6—Industrial Toxicology—Richard Cohen, MD, MPH, and Kameron Balzer, CIH
7—Gases, Vapors, and Solvents—George S. Fulton, MS, CIH
8—Particulates—Theodore J. Hogan, PhD, CIH
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11—Nonionizing Radiation—Gordon Miller, CIH
12—Thermal Stress—Thomas E. Bernard, PhD, CIH
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14—Biological Hazards—A. Lynn Harding, MPH, Diane O. Fleming, PhD, and Janet M. Macher, ScD, MPH
15—Evaluation—Elizabeth R. Gross, CIH, Elise Pechter, CIH
16—Air-Sampling—Maureen A. Huey, MPH, CIH
17—Direct-Reading Instruments for Gases, Vapors, and Particulates—Rolfe M.A. Hahne, PhD, CIH
18—Methods of Control—Susan M. Raterman, CIH, REPA
19—Local Exhaust Ventilation of Industrial Occupancies—D. Jeff Burton, PE, CIH, CSP

20—General Ventilation of Industrial Occupancies—D. Jeff Burton, PE, CIH, CSP
21—General Ventilation of Nonindustrial Occupancies—D. Jeff Burton, PE, CIH, CSP
22—Respiratory Protection—Craig E. Colton, CIH
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We would also like to thank Ron Miller and George Kraficsin, who reviewed material for the fifth edition: special thanks to Patty Quinlan and Jodey Schonfeld, whose excellent work, tireless attention to technical detail, and professionalism, helped to make this edition the best yet.

And finally, this book is dedicated to my family, Michael and Max, who again supported having "the book" in our lives over the past two years; and my mother and father, Doris and Henry Plog; and to the working women and men who are, after all, the point of it all.

Because this manual will be revised periodically, contributions and comments from readers are welcome.

BARBARA A. PLOG, MPH, CIH, CSP
EDITOR IN CHIEF
DECEMBER 2001

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Prior to this post, Rick was the Supervisor of Industrial Hygiene and Safety at the University of California at Berkeley. He was also the founder and interim director of an EPA-grant initiated health and safety training program at the University of California-Berkeley Extension. He is widely recognized as an expert on peroxidizable chemicals and perchlorate-contaminated ventilation system testing and demolition.

Peggy F. Kivel, CIH, is a Certified Industrial Hygienist with more than 18 years of experience in the field of industrial hygiene. She has served as the Regional Manager for IHI Environmental in the San Francisco Bay Area for the past 12 years. Ms. Kivel has extensive experience in the areas of worker exposure assessments, indoor air quality investigations and hazardous materials management. Prior to working at IHI Environmental, Ms. Kivel was a Staff Industrial Hygienist at IBM Corporation in San Jose, California, providing support for major manufacturing, development and research divisions. She has a Bachelor of Arts degree from the University of California-Berkeley.

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Ergonomist, CPE. Fellow, HFES and ES; a member of the AIHA; and an honorary member, International Society for Occupational Ergonomics and Safety. He has written more than 200 publications and obtained two patents. His international consulting experience includes work in engineering anthropometry, applied physiology, biomechanics, human factors engineering, and office ergonomics.

Janet Macher ScD, MPH, is an air pollution research specialist with the California Department of Health Services. She has a Master's Degree from the University of California and doctorate from Harvard University with emphasis on industrial hygiene, public health, and microbiology. Dr. Macher studies engineering measures to control airborne infectious and hypersensitivity diseases, evaluates methods to collect and identify airborne biological material, and participates in investigations of bioaerosol-related illnesses in the state of California.

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Barbara A Plog, MPH, CIH, CSP, is a Certified Industrial Hygienist and a Certified Safety Professional and has been in the field of occupational health for 20 years. She is the Director of the Continuing Professional Education Program of the Center for Occupational and Environmental Health (COEH) at the University of California-Berkeley School of Public Health. COEH is a NIOSH Education and Research Center. Ms Plog is a Lecturer in the School of Public Health's industrial hgyiene program and an assistant clinical professor at the University of California-San Francisco School of Nursing's Occupational Health Nursing program. She teaches Industrial Hygiene and Occupational Safety to graduate students in industrial hygiene and occupational health nursing. She also serves as the Associate Director for Technical Services for the Labor Occupational Health Program and is the Technical Director and Principal Investigator for the Lead-Safe Schools Program. She holds a Masters of Public Health Degree in Industrial Hygiene from the University of Illinois School of Public Health. Before coming to the University of California-Berkeley in 1987, Ms. Plog was manager of Occupational Health at the National Safety Council for five years. She is editor-in-chief of the 1,000-plus page textbook, *Fundamentals of Industrial Hygiene,* 3rd, 4th, and 5th editions.

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History and Development

Part I

Chapter 1

Overview of Industrial Hygiene

by Barbara A. Plog, MPH, CIH, CSP

Industrial hygiene is that science and art devoted to the anticipation, recognition, evaluation, and control of those environmental factors or stresses arising in or from the workplace that may cause sickness, impaired health and well-being, or significant discomfort among workers or among the citizens of the community. Industrial hygienists are occupational health professionals who are concerned primarily with the control of environmental stresses or occupational health hazards that arise as a result of or during the course of work. The industrial hygienist recognizes that environmental stresses may endanger life and health, accelerate the aging process, or cause significant discomfort.

The industrial hygienist, although trained in engineering, physics, chemistry, environmental sciences, safety, or biology, has acquired through postgraduate study or experience a knowledge of the health effects of chemical, physical, biological, and ergonomic agents. The industrial hygienist is involved in the monitoring and analysis required to detect the extent of exposure, and the engineering and other methods used for hazard control.

Evaluation of the magnitude of work-related environmental hazards and stresses is done by the industrial hygienist, aided by training, experience, and quantitative measurement of the chemical, physical, ergonomic, or biological stresses. The industrial hygienist can thus give an expert opinion as to the degree of risk the environmental stresses pose.

Industrial hygiene includes the development of corrective measures in order to control health hazards by either reducing or eliminating the exposure. These control procedures may include the substitution of harmful or toxic materials with less dangerous ones, changing of work processes to eliminate or minimize work exposure, installation of exhaust ventilation systems, good housekeeping (including appropriate waste disposal methods), and the provision of proper personal protective equipment.

An effective industrial hygiene program involves the anticipation and recognition of health hazards arising from work operations and processes, evaluation and measurement of the

magnitude of the hazard (based on past experience and study), and control of the hazard.

Occupational health hazards *may mean conditions that cause legally compensable illnesses, or may mean any conditions in the workplace that impair the health of employees enough to make them lose time from work or to cause significant discomfort. Both are undesirable. Both are preventable. Their correction is properly a responsibility of management.*

PROFESSIONAL ETHICS

In late 1994, the four major U.S. industrial hygiene organizations gave final endorsements to a revised Code of Ethics for the Practice of Industrial Hygiene. These organizations are the American Conference of Governmental Industrial Hygienists (ACGIH), the American Academy of Industrial Hygiene (AAIH), the American Board of Industrial Hygiene (ABIH), and the American Industrial Hygiene Association (AIHA).

The new code defines practice standards (Canons of Ethical Conduct) and applications (interpretive guidelines). The Canons of Ethical Conduct are as follows:

Industrial Hygienists shall practice their profession following recognized scientific principles with the realization that the lives, health, and well-being of people may depend upon their professional judgment and that they are obligated to protect the health and well-being of people.

Industrial Hygienists shall counsel affected parties factually regarding potential health risks and precautions necessary to avoid adverse health effects.

Industrial Hygienists shall keep confidential personal and business information obtained during the exercise of industrial hygiene activities, except when required by law or overriding health and safety considerations.

Industrial Hygienists shall avoid circumstances where a compromise of professional judgment or conflict of interest may arise.

Industrial Hygienists shall perform services only in the areas of their competence.

Industrial Hygienists shall act responsibly to uphold the integrity of the profession.

The interpretive guidelines to the Canons of Ethical Conduct are a series of statements that amplify the code (Figure 1–1).

The Occupational Health and Safety Team

The chief goal of an occupational health and safety program in a facility is to prevent occupational injury and illness by anticipating, recognizing, evaluating, and controlling occupational health and safety hazards. The medical, industrial hygiene, and safety programs may have distinct, additional program goals but all programs interact and are often considered different components of the overall health and safety program. The occupational health and safety team consists, then, of the industrial hygienist, the safety professional, the occupational health nurse, the occupational medicine physician, the employees, senior and line management, and others depending on the size and character of the particular facility. All team members must act in concert to provide information and activities, supporting the other parts to achieve the overall goal of a healthy and safe work environment. Therefore, the separate functions must be administratively linked in order to effect a successful and smoothly run program.

The first vital component to an effective health and safety program is the commitment of *senior management* and *line management*. Serious commitment is demonstrated when management is visibly involved in the program both by management support and personal compliance with all health and safety practices. Equally critical is the assignment of the authority, as well as the responsibility, to carry out the health and safety program. The health and safety function must be given the same level of importance and accountability as the production function.

The function of the *industrial hygienist* has been defined above. (Also see Chapter 23, The Industrial Hygienist.) The industrial hygiene program must be made up of several key components: a written program/policy statement, hazard recognition procedures, hazard evaluation and exposure assessment, hazard control, employee training, employee involvement, program evaluation and audit, and recordkeeping. (See Chapter 27, The Industrial Hygiene Program, for further discussion.)

The *safety professional* must draw upon specialized knowledge in the physical and social sciences. Knowledge of engineering, physics, chemistry, statistics, mathematics, and principles of measurement and analysis is integrated in the evaluation of safety performance. The safety professional must thoroughly understand the factors contributing to accident occurrence and combine this with knowledge of motivation, behavior, and communication in order to devise methods and procedures to control safety hazards. Because the practice of the safety professional and the industrial hygienist are so closely related, it is rare to find a safety professional who does not practice some traditional industrial hygiene and vice versa. At times, the safety and industrial hygiene responsibilities may be vested in the same individual or position. (See Chapter 24, The Safety Professional.)

The *occupational health nurse* (OHN) is the key to the delivery of comprehensive health care services to workers. Occupational health nursing is focused on the promotion, protection, and restoration of workers' health within the context of a safe and healthy work environment. The OHN provides the critical link between the employee's health status, the work process, and the determination of employee ability to do the job. Knowledge of health and safety regulations, workplace hazards, direct care skills, counseling, teaching, and program management are but a few of the key knowledge areas for the OHN, with strong communication

Code of Ethics for the Practice of Industrial Hygiene

Objective

These canons provide standards of ethical conduct for Industrial Hygienists as they practice their profession and exercise their primary mission, to protect the health and well-being of working people and the public from chemical, microbiological, and physical health hazards present at, or emanating from, the workplace.

Canons of ethical conduct

CANON 1

Industrial Hygienists shall practice their profession following recognized scientific principles with the realization that the lives, health, and well-being of people may depend upon their professional judgment and that they are obligated to protect the health and well-being of people.

INTERPRETIVE GUIDELINES

- Industrial Hygienists should base their professional opinions, judgments, interpretations of findings, and recommendations upon recognized scientific principles and practices which preserve and protect the health and well-being of people.
- Industrial Hygienists shall not distort, alter, or hide facts in rendering professional opinions or recommendations.
- Industrial Hygienists shall not knowingly make statements that misrepresent or omit facts.

CANON 2

Industrial Hygienists shall counsel affected parties factually regarding potential health risks and precautions necessary to avoid adverse health effects.

INTERPRETIVE GUIDELINES

- Industrial Hygienists should obtain information regarding potential health risks from reliable sources.
- Industrial Hygienists should review the pertinent, readily available information to factually inform the affected parties.
- Industrial Hygienists should initiate appropriate measures to see that the health risks are effectively communicated to the affected parties.
- Parties may include management, clients, employees, contractor employees, or others, dependent on circumstances at the time.

CANON 3

Industrial Hygienists shall keep confidential personal and business information obtained during the exercise of industrial hygiene activities, except when required by law or overriding health and safety considerations.

INTERPRETIVE GUIDELINES

- Industrial Hygienists should report and communicate information which is necessary to protect the health and safety of workers and the community.
- If their professional judgment is overruled under circumstances where the health and lives of people are endangered, Industrial Hygienists shall notify their employer, client, or other such authority, as may be appropriate.
- Industrial Hygienists should release confidential personal or business information only with the information owners express authorization, except when there is a duty to disclose information as required by law or regulation.

CANON 4

Industrial Hygienists shall avoid circumstances where a compromise of professional judgment or conflict of interest may arise.

INTERPRETIVE GUIDELINES

- Industrial Hygienists should promptly disclose known or potential conflicts of interest to parties that may be affected.
- Industrial Hygienists shall not solicit or accept financial or other valuable consideration from any party, directly or indirectly, which is intended to influence professional judgment.
- Industrial Hygienists shall not offer any substantial gift, or other valuable consideration, in order to secure work.
- Industrial Hygienists should advise their clients or employer when they initially believe a project to improve industrial hygiene conditions will not be successful.
- Industrial Hygienists should not accept work that negatively impacts the ability to fulfill existing commitments.
- In the event that this Code of Ethics appears to conflict with another professional code to which Industrial Hygienists are bound, they will resolve the conflict in the manner that protects the health of affected parties.

CANON 5

Industrial Hygienists shall perform services only in the areas of their competence.

INTERPRETIVE GUIDELINES

- Industrial Hygienists should undertake to perform services only when qualified by education, training, or experience in the specific technical fields involved, unless sufficient assistance is provided by qualified associates, consultants, or employees.
- Industrial Hygienists shall obtain appropriate certifications, registrations, and/or licenses as required by federal, state, and/or local regulatory agencies prior to providing industrial hygiene services, where such credentials are required.
- Industrial Hygienists shall affix or authorize the use of their seal, stamp, or signature only when the document is prepared by the Industrial Hygienist or someone under their direction and control.

CANON 6

Industrial Hygienists shall act responsibly to uphold the integrity of the profession.

INTERPRETIVE GUIDELINES

- Industrial Hygienists shall avoid conduct or practice which is likely to discredit the profession or deceive the public.
- Industrial Hygienists shall not permit use of their name or firm name by any person or firm which they have reason to believe is engaging in fraudulent or dishonest industrial hygiene practices.
- Industrial Hygienists shall not use statements in advertising their expertise or services containing a material misrepresentation of fact or omitting a material fact necessary to keep statements from being misleading.
- Industrial Hygienists shall not knowingly permit their employees, employers, or others to misrepresent the individuals' professional background, expertise, or services which are misrepresentations of fact.
- Industrial Hygienists shall not misrepresent their professional education, experience, or credentials.

Figure 1–1. The joint Code of Ethics for the Practice of Industrial Hygiene endorsed by the AIHA, the ABIH, the AAIH, and the ACGIH. (From *ACGIH Today!* 3(1), January 1995.) These guidelines may be supplemented when necessary, as ethical issues and claims arise.

skills of the utmost importance. OHNs deliver high-quality care at worksites and support the primary prevention dictum that most workplace injuries and illnesses are preventable. If injuries occur, OHNs use a case-management approach to return injured employees to appropriate work on a timely basis. The OHN often functions in multiple roles within one job position, including clinician, educator, manager, and consultant. (See Chapter 26, The Occupational Health Nurse.)

The *occupational medicine physician* has acquired, through graduate training or experience, extensive knowledge of cause and effect relationships of chemical, physical, biological, and ergonomic hazards, the signs and symptoms of chronic and acute exposures, and the treatment of adverse effects. The primary goal of the occupational medicine physician is to prevent occupational illness and, when illness occurs, to restore employee health within the context of a healthy and safe workplace. Many regulations provide for a minimum medical surveillance program and specify mandatory certain tests and procedures.

The occupational medicine physician and the occupational health nurse should be familiar with all jobs, materials, and processes used. An occasional workplace inspection by the medical team enables them to suggest protective measures and aids them in recommending placement of employees in jobs best suited to their physical capabilities. (See discussion of the Americans with Disabilities Act in Chapter 26, The Occupational Health Nurse.)

Determining the work-relatedness of disease is another task for the occupational medicine physician. The industrial hygienist provides information about the manufacturing operations and work environment of a company to the medical department as well. In many cases it is extremely difficult to differentiate between the symptoms of occupational and nonoccupational disease. The industrial hygienist supplies information on the work operations and their associated hazards and enables the medical department to correlate the employee's condition and symptoms with potential workplace health hazards.

The *employee* plays a major role in the occupational health and safety program. Employees are excellent sources of information on work processes and procedures and the hazards of their daily operations. Industrial hygienists benefit from this source of information and often obtain innovative suggestions for controlling hazards.

The *safety and health committee* provides a forum for securing the cooperation, coordination, and exchange of ideas among those involved in the health and safety program. It provides a means of involving employees in the program. The typical functions of the safety and health committee include, among others, to examine company safety and health issues and recommend policies to management, conduct periodic workplace inspections, and evaluate and promote interest in the health and safety program. Joint labor–management safety and health committees are often used where employees are represented by a union. The committee meetings also present an opportunity to discuss key industrial hygiene program concerns and to formulate appropriate policies.

FEDERAL REGULATIONS

Before 1970, government regulation of health and safety matters was largely the concern of state agencies. There was little uniformity in codes and standards or in the application of these standards. Almost no enforcement procedures existed.

On December 29, 1970, the Occupational Safety and Health Act, known as the OSHAct, was enacted by Congress. Its purpose was to "assure so far as possible every working man and woman in the nation safe and healthful working conditions and to preserve our human resources." The OSHAct sets out two duties for employers:

- Each employer shall furnish to each employee a place of employment, which is free from recognized hazards that are causing or are likely to cause death or serious harm to their employees.
- Each employer shall comply with occupational safety and health standards under the Act.

For employees, the OSHAct states that "Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to the Act which are applicable to his own actions and conduct."

The Occupational Safety and Health Administration (OSHA) came into official existence on April 28, 1971, the date the OSHAct became effective. It is housed within the U.S. Department of Labor. The OSHAct also established the National Institute for Occupational Safety and Health (NIOSH), which is housed within the Centers for Disease Control and Prevention (CDC). The CDC is part of the U.S. Public Health Service.

OSHA was empowered to promulgate safety and health standards with technical advice from NIOSH. OSHA is empowered to enter workplaces to investigate alleged violations of these standards and to perform routine inspections. Formal complaints of standards violations may be made by employees or their representatives. The OSHAct also gives OSHA the right to issue citations and penalties, provide for employee walkarounds or interview of employees during the inspection, require employers to maintain accurate records of exposures to potentially hazardous materials, and to inform employees of the monitoring results. OSHA is also empowered to provide up to 50/50 funding with states that wish to establish state OSHA programs that are at least as effective as the federal program. As of this date, there are 23 approved state plans and approved plans from Puerto Rico and the Virgin Islands.

NIOSH is the principal federal agency engaged in occupational health and safety research. The agency is responsible for identifying hazards and making recommendations for

regulations. These recommendations are called Recommended Exposure Limits (RELs). NIOSH also issues criteria documents and health hazard alerts on various hazards and is responsible for testing and certifying respiratory protective equipment.

Part of NIOSH research takes place during activities called *Health Hazard Evaluations*. These are on-the-job investigations of reported worker exposures that are carried out in response to a request by either the employer or the employee or employee representative. In addition to its own research program, NIOSH also funds supportive research activities at a number of universities, colleges, and private facilities.

NIOSH has training grant programs in colleges and universities across the nation. These are located at designated Education and Research Centers (ERCs). ERCs train occupational medicine physicians, occupational health nurses, industrial hygienists, safety professionals, ergonomists, and others in the safety and health field. They also provide continuing professional education for practicing occupational health and safety professionals. (See Chapter 28, Government Regulations, and Chapter 29, History of the Federal Occupational Safety and Health Administration, for a full discussion of federal agencies and regulations.)

ENVIRONMENTAL FACTORS OR STRESSES

The various environmental factors or stresses that can cause sickness, impaired health, or significant discomfort in workers can be classified as chemical, physical, biological, or ergonomic.

Chemical hazards. These arise from excessive airborne concentrations of mists, vapors, gases, or solids in the form of dusts or fumes. In addition to the hazard of inhalation, some of these materials may act as skin irritants or may be toxic by absorption through the skin.

Physical hazards. These include excessive levels of nonionizing radiation (see Chapter 10), ionizing radiation (see Chapter 11), noise (see Chapter 9), vibration, and extremes of temperature (see Chapter 12) and pressure.

Ergonomic hazards. These include improperly designed tools, work areas, or work procedures. Improper lifting or reaching, poor visual conditions, or repeated motions in an awkward position can result in accidents or illnesses in the occupational environment. Designing the tools and the job to fit the worker is of prime importance. Engineering and biomechanical principles must be applied to eliminate hazards of this kind (see Chapter 13).

Biological hazards. These are any living organism or its properties that can cause an adverse response in humans. They can be part of the total environment or associated with a particular occupation. Work-related illnesses due to biological agents have been widely reported, but in many workplaces their presence and resultant illness are not well recognized. It is estimated that the population at risk for occupational biohazards may be several hundred million workers worldwide (see Chapter 14).

Exposure to many of the harmful stresses or hazards listed can produce an immediate response due to the intensity of the hazard, or the response can result from longer exposure at a lower intensity.

In certain occupations, depending on the duration and severity of exposure, the work environment can produce significant subjective responses or strain. The energies and agents responsible for these effects are called environmental stresses. An employee is most often exposed to an intricate interplay of many stresses, not to a single environmental stress.

Chemical Hazards

The majority of occupational health hazards arise from inhaling chemical agents in the form of vapors, gases, dusts, fumes, and mists, or by skin contact with these materials. The degree of risk of handling a given substance depends on the magnitude and duration of exposure. (See Chapter 15, Evaluation, for more details.)

To recognize occupational factors or stresses, a health and safety professional must first know about the chemicals used as raw materials and the nature of the products and by-products manufactured. This sometimes requires great effort. The required information can be obtained from the Material Safety Data Sheet (MSDS) (Figure 1–2) that must be supplied by the chemical manufacturer or importer for all hazardous materials under the OSHA hazard communication standard. The MSDS is a summary of the important health, safety, and toxicological information on the chemical or the mixture ingredients. Other stipulations of the hazard communication standard require that all containers of hazardous substances in the workplace be labeled with appropriate warning and identification labels. See Chapter 28, Government Regulations, and Chapter 29, History of the Federal Occupational Safety and Health Administration, for further discussion of the hazard communication standard.

If the MSDS or the label does not give complete information but only trade names, it may be necessary to contact the manufacturer to obtain this information.

Many industrial materials such as resins and polymers are relatively inert and nontoxic under normal conditions of use, but when heated or machined, they may decompose to form highly toxic by-products. Information about these hazardous products and by-products must also be included in the company's hazard communication program.

Breathing of some materials can irritate the upper respiratory tract or the terminal passages of the lungs and the air sacs, depending upon the solubility of the material. Contact of irritants with the skin surface can produce various kinds of dermatitis.

The presence of excessive amounts of biologically inert gases can dilute the atmospheric oxygen below the level required to maintain the normal blood saturation value for oxygen and disturb cellular processes. Other gases and vapors can prevent the blood from carrying oxygen to the tissues or interfere with its transfer from the blood to the tissue, thus producing chemical asphyxia or suffocation. Carbon monoxide and hydrogen cyanide are examples of chemical asphyxiants.

Some substances may affect the central nervous system and brain to produce narcosis or anesthesia. In varying degrees, many solvents have these effects. Substances are often classified, according to the major reaction they produce, as asphyxiants, systemic toxins, pneumoconiosis-producing agents, carcinogens, irritant gases, and so on.

SOLVENTS

This section discusses some general hazards arising from the use of solvents; a more detailed description is given in Chapter 7, Gases, Vapors, and Solvents.

Solvent vapors enter the body mainly by inhalation, although some skin absorption can occur. The vapors are absorbed from the lungs into the blood and are distributed mainly to tissues with a high content of fat and lipids, such as the central nervous system, liver, and bone marrow. Solvents include aliphatic and aromatic hydrocarbons, alcohols, aldehydes, ketones, chlorinated hydrocarbons, and carbon disulfide.

Occupational exposure can occur in many different processes, such as the degreasing of metals in the machine industry and the extraction of fats or oils in the chemical or food industry, dry cleaning, painting, and the plastics industry.

The widespread industrial use of solvents presents a major problem to the industrial hygienist, the safety professional, and others responsible for maintaining a safe, healthful working environment. Getting the job done using solvents without hazard to employees or property depends on the proper selection, application, handling, and control of solvents and an understanding of their properties.

A working knowledge of the physical properties, nomenclature, and effects of exposure is absolutely necessary in making a proper assessment of a solvent exposure. Nomenclature can be misleading. For example, benzine is sometimes mistakenly called benzene, a completely different solvent. Some commercial grades of benzine may contain benzene as a contaminant.

Use the information on the MSDS (Figure 1–2) or the manufacturer's label for the specific name and composition of the solvents involved.

The severity of a hazard in the use of organic solvents and other chemicals depends on the following factors:

- ➢ How the chemical is used
- ➢ Type of job operation, which determines how the workers are exposed
- ➢ Work pattern
- ➢ Duration of exposure
- ➢ Operating temperature
- ➢ Exposed liquid surface
- ➢ Ventilation rates
- ➢ Evaporation rate of solvent
- ➢ Pattern of airflow
- ➢ Concentration of vapor in workroom air
- ➢ Housekeeping

The hazard is determined not only by the toxicity of the solvent or chemical itself but by the conditions of its use (who, what, how, where, and how long).

The health and safety professional can obtain much valuable information by observing the manner in which health hazards are generated, the number of people involved, and the control measures in use.

After the list of chemicals and physical conditions to which employees are exposed has been prepared, determine which of the chemicals or agents may result in hazardous exposures and need further study.

Dangerous materials are chemicals that may, under specific circumstances, cause injury to persons or damage to property because of reactivity, instability, spontaneous decomposition, flammability, or volatility. Under this definition, we will consider substances, mixtures, or compounds that are explosive, corrosive, flammable, or toxic.

Explosives are substances, mixtures, or compounds capable of entering into a combustion reaction so rapidly and violently as to cause an explosion.

Corrosives are capable of destroying living tissue and have a destructive effect on other substances, particularly on combustible materials; this effect can result in a fire or explosion.

Flammable liquids are liquids with a flash point of 100 F (38 C) or less, although those with higher flash points can be both combustible and dangerous.

Toxic chemicals are gases, liquids, or solids that, through their chemical properties, can produce injurious or lethal effects on contact with body cells.

Oxidizing materials are chemicals that decompose readily under certain conditions to yield oxygen. They may cause a fire in contact with combustible materials, can react violently with water, and when involved in a fire can react violently.

Dangerous gases are those that can cause lethal or injurious effects and damage to property by their toxic, corrosive, flammable, or explosive physical and chemical properties.

Storage of dangerous chemicals should be limited to one day's supply, consistent with the safe and efficient operation of the process. The storage should comply with applicable local laws and ordinances. An approved storehouse should be provided for the main supply of hazardous materials.

For hazardous materials, MSDSs can be consulted for toxicological information. The information is useful to the medical, purchasing, managerial, engineering, and health and safety departments in setting guidelines for safe use of these materials. This information is also very helpful in an emergency. The information should cover materials actually

Material Safety Data Sheet

May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*

Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

Section I

Manufacturer's Name	Emergency Telephone Number
Address *(Number, Street, City, State, and ZIP Code)*	Telephone Number for Information
	Date Prepared
	Signature of Preparer *(optional)*

Section II — Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% *(optional)*

Section III — Physical/Chemical Characteristics

Boiling Point		Specific Gravity (H_2O = 1)	
Vapor Pressure (mm Hg.)		Melting Point	
Vapor Density (AIR = 1)		Evaporation Rate (Butyl Acetate = 1)	

Solubility in Water

Appearance and Odor

Section IV — Fire and Explosion Hazard Data

Flash Point (Method Used)	Flammable Limits	LEL	UEL

Extinguishing Media

Special Fire Fighting Procedures

Unusual Fire and Explosion Hazards

(Reproduce locally) OSHA 174, Sept. 1985

Figure 1–2. Material Safety Data Sheet. Its format meets the requirements of the federal hazard communication standard. (Continues)

Section V — Reactivity Data

Stability	Unstable		Conditions to Avoid
	Stable		

Incompatibility (*Materials to Avoid*)

Hazardous Decomposition or Byproducts

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur		

Section VI — Health Hazard Data

Route(s) of Entry: Inhalation? Skin? Ingestion?

Health Hazards (*Acute and Chronic*)

Carcinogenicity: NTP? IARC Monographs? OSHA Regulated?

Signs and Symptoms of Exposure

Medical Conditions
Generally Aggravated by Exposure

Emergency and First Aid Procedures

Section VII — Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled

Waste Disposal Method

Precautions to Be Taken in Handling and Storing

Other Precautions

Section VIII — Control Measures

Respiratory Protection (*Specify Type*)

Ventilation	Local Exhaust	Special
	Mechanical (*General*)	Other

Protective Gloves	Eye Protection

Other Protective Clothing or Equipment

Work/Hygienic Practices

Page 2

☆ USGPO 1986-491-529/45775

Figure 1–2. (Continued)

in use and those that may be contemplated for early future use. Possibly the best and earliest source of information concerning such materials is the purchasing agent. Thus, a close liaison should be set up between the purchasing agent and health and safety personnel so that early information is available concerning materials in use and those to be ordered, and to ensure that MSDSs are received and reviewed for all hazardous substances.

TOXICITY VERSUS HAZARD

The toxicity of a material is not synonymous with its hazard. *Toxicity* is the capacity of a material to produce injury or harm when the chemical has reached a sufficient concentration at a certain site in the body. *Hazard* is the probability that this concentration in the body will occur. This degree of hazard is determined by many factors or elements. (See Chapter 6, Industrial Toxicology.)

The key elements to be considered when evaluating a health hazard are as follows:

- ➢ What is the route of entry of the chemical into the body?
- ➢ How much of the material must be in contact with a body cell and for how long to produce injury?
- ➢ What is the probability that the material will be absorbed or come in contact with body cells?
- ➢ What is the rate of generation of airborne contaminants?
- ➢ What control measures are in place?

The effects of exposure to a substance depend on dose, rate, physical state of the substance, temperature, site of absorption, diet, and general state of a person's health.

Physical Hazards

Problems caused by such things as noise, temperature extremes, ionizing radiation, nonionizing radiation, and pressure extremes are physical stresses. It is important that the employer, supervisor, and those responsible for safety and health be alert to these hazards because of the possible immediate or cumulative effects on the health of employees.

NOISE

Noise (unwanted sound) is a form of vibration conducted through solids, liquids, or gases. The effects of noise on humans include the following:

- ➢ Psychological effects (noise can startle, annoy, and disrupt concentration, sleep, or relaxation)
- ➢ Interference with speech communication and, as a consequence, interference with job performance and safety
- ➢ Physiological effects (noise-induced hearing loss, or aural pain when the exposure is severe)

Damage risk criteria. If the ear is subjected to high levels of noise for a sufficient period of time, some loss of hearing may occur. A number of factors can influence the effect of the noise exposure:

- ➢ Variation in individual susceptibility
- ➢ Total energy of the sound
- ➢ Frequency distribution of the sound
- ➢ Other characteristics of the noise exposure, such as whether it is continuous, intermittent, or made up of a series of impacts
- ➢ Total daily duration of exposure
- ➢ Length of employment in the noise environment

Because of the complex relationships of noise and exposure time to threshold shift (reduction in hearing level) and the many contributory causes, establishing criteria for protecting workers against hearing loss is difficult. However, criteria have been developed to protect against hearing loss in the speech-frequency range. These criteria are known as the Threshold Limit Values for Noise. (See Chapter 9, Industrial Noise, and Appendix B, The ACGIH Threshold Limit Values and Biological Exposure Indices, for more details.)

There are three nontechnical guidelines to determine whether the work area has excessive noise levels:

- ➢ If it is necessary to speak very loudly or shout directly into the ear of a person in order to be understood, it is possible that the exposure limit for noise is being exceeded. Conversation becomes difficult when the noise level exceeds 70 decibels (dBA).
- ➢ If employees say that they have heard ringing noises in their ears at the end of the workday, they may be exposed to too much noise.
- ➢ If employees complain that the sounds of speech or music seem muffled after leaving work, but that their hearing is fairly clear in the morning when they return to work, they may be exposed to noise levels that cause a partial temporary loss of hearing, which can become permanent with repeated exposure.

Permissible levels. The criteria for hearing conservation, required by OSHAct in 29 *CFR* 1910.95, establishes the permissible levels of harmful noise to which an employee may be subjected. The permissible decibel levels and hours (duration per day) are specified. For example, a noise level of 90 dBA is permissible for eight hours, 95 dBA for four hours, etc. (See Chapter 9, Industrial Noise, for more details.)

The regulations stipulate that when employees are subjected to sound that exceeds the permissible limits, feasible administrative or engineering controls shall be used. If such controls fail to reduce sound exposure within permissible levels, personal protective equipment must be provided and used to reduce sound levels to within permissible levels.

According to the Hearing Conservation Amendment to 29 *CFR* 1910.95, in all cases when the sound levels exceed 85 dBA on an eight-hour time-weighted average (TWA), a continuing, effective hearing conservation program shall be administered. The Hearing Conservation Amendment specifies the essential elements of a hearing conservation program. (See Chapter 9, Industrial Noise, for a discussion of noise and OSHA noise regulations.)

Administering a hearing conservation program goes beyond the wearing of earplugs or earmuffs. Such programs

can be complex, and professional guidance is essential for establishing programs that are responsive to the need. Valid noise exposure information correlated with audiometric tests results is needed to help health and safety and medical personnel to make informed decisions about hearing conservation programs.

The effectiveness of a hearing conservation program depends on the cooperation of employers, employees, and others concerned. Management's responsibility in such a program includes noise measurements, initiation of noise control measures, provision of hearing protection equipment, audiometric testing of employees to measure their hearing levels (thresholds), and information and training programs for employees.

The employee's responsibility is to properly use the protective equipment provided by management, and to observe any rules or regulations on the use of equipment in order to minimize noise exposure.

EXTREMES OF TEMPERATURE

Probably the most elementary factor of environmental control is control of the thermal environment in which people work. Extremes of temperature, or thermal stress, affect the amount of work people can do and the manner in which they do it. In industry, the problem is more often high temperatures rather than low temperatures. (More details on this subject are given in Chapter 12, Thermal Stress.)

The body continuously produces heat through its metabolic processes. Because the body processes are designed to operate only within a very narrow range of temperature, the body must dissipate this heat as rapidly as it is produced if it is to function efficiently. A sensitive and rapidly acting set of temperature-sensing devices in the body must also control the rates of its temperature-regulating processes. (This mechanism is described in Chapter 3, The Skin and Occupational Dermatoses.)

Heat stress is a common problem, as are the problems presented by a very cold environment. Evaluation of heat stress in a work environment is not simple. Considerably more is involved than simply taking a number of air-temperature measurements and making decisions on the basis of this information.

One question that must be asked is whether the temperature is merely causing discomfort or whether continued exposure will cause the body temperature to fall below or rise above safe limits. It is difficult for a person with only a clipboard full of data to interpret how another person actually feels or is adversely affected.

People function efficiently only in a very narrow body temperature range, a core temperature measured deep inside the body, not on the skin or at body extremities. Fluctuations in core temperatures exceeding 2 F below or 3 F above the normal core temperature of 99.6 F (37.6 C), which is 98.6 F (37 C) mouth temperature, impair performance markedly. If this five-degree range is exceeded, a health hazard exists.

The body attempts to counteract the effects of high temperature by increasing the heart rate. The capillaries in the skin also dilate to bring more blood to the surface so that the rate of cooling is increased. Sweating is an important factor in cooling the body.

Heatstroke is caused by exposure to an environment in which the body is unable to cool itself sufficiently. Heatstroke is a much more serious condition than heat cramps or heat exhaustion. An important predisposing factor is excessive physical exertion or moderate exertion in extreme heat conditions. The method of control is to reduce the temperature of the surroundings or to increase the ability of the body to cool itself, so that body temperature does not rise. In heatstroke, sweating may cease and the body temperature can quickly rise to fatal levels. It is critical to undertake emergency cooling of the body even while medical help is on the way. Studies show that the higher the body temperature on admission to emergency rooms, the higher the fatality rate. Heatstroke is a life-threatening medical emergency.

Heat cramps can result from exposure to high temperature for a relatively long time, particularly if accompanied by heavy exertion, with excessive loss of salt and moisture from the body. Even if the moisture is replaced by drinking plenty of water, an excessive loss of salt can cause heat cramps or heat exhaustion.

Heat exhaustion can also result from physical exertion in a hot environment. Its signs are a mildly elevated temperature, pallor, weak pulse, dizziness, profuse sweating, and cool, moist skin.

ENVIRONMENTAL MEASUREMENTS

In many heat stress studies, the variables commonly measured are work energy metabolism (often estimated rather than measured), air movement, air temperature, humidity, and radiant heat. See Chapter 12, Thermal Stress, for illustrations and more details.

Air movement is measured with some type of anemometer and the air temperature with a thermometer, often called a *dry bulb thermometer*.

Humidity, or the moisture content of the air, is generally measured with a psychrometer, which gives both dry bulb and wet bulb temperatures. Using these temperatures and referring to a psychrometric chart, the relative humidity can be established.

The term *wet bulb* is commonly used to describe the temperature obtained by having a wet wick over the mercury-well bulb of an ordinary thermometer. Evaporation of moisture in the wick, to the extent that the moisture content of the surrounding air permits, cools the thermometer to a temperature below that registered by the dry bulb. The combined readings of the dry bulb and wet bulb thermometers are then used to calculate percent relative humidity, absolute moisture content of the air, and water vapor pressure.

Radiant heat is a form of electromagnetic energy similar to light but of longer wavelength. Radiant heat (from such

sources as red-hot metal, open flames, and the sun) has no appreciable heating effect on the air it passes through, but its energy is absorbed by any object it strikes, thus heating the person, wall, machine, or whatever object it falls on. Protection requires placing opaque shields or screens between the person and the radiating surface.

An ordinary dry bulb thermometer alone will not measure radiant heat. However, if the thermometer bulb is fixed in the center of a metal toilet float that has been painted dull black, and the top of the thermometer stem protrudes outside through a one-hole cork or rubber stopper, radiant heat can be measured by the heat absorbed in this sphere. This device is known as a globe thermometer.

Heat loss. Conduction is an important means of heat loss when the body is in contact with a good cooling agent, such as water. For this reason, when people are immersed in cold water, they become chilled much more rapidly and effectively than when exposed to air of the same temperature.

Air movement cools the body by convection: The moving air removes the air film or the saturated air (which is formed very rapidly by evaporation of sweat) and replaces it with a fresh air layer capable of accepting more moisture from the skin.

Heat stress indices. The methods commonly used to estimate heat stress relate various physiological and environmental variables and end up with one number that then serves as a guide for evaluating stress. For example, the effective temperature index combines air temperature (dry bulb), humidity (wet bulb), and air movement to produce a single index called an effective temperature.

Another index is the wet bulb globe temperature (WBGT). The numerical value of the WBGT index is calculated by the following equations.

Indoors or outdoors with no solar loads:

$$WBGT_{in} = 0.7\ T_{nwb} + 0.3\ T_{gt}$$

Outdoors with solar load:

$$WBGT_{out} = 0.7\ T_{nwb} + 0.2\ T_{gt} + 0.1\ T_{db}$$

where

T_{nwb} = natural wet bulb temperature
T_{gt} = globe temperature
T_{db} = dry bulb temperature

In its *Criteria Document on Hot Environments* (see Bibliography), NIOSH states that when impermeable clothing is worn, the WBGT should not be used because evaporative cooling would be limited. The WBGT combines the effects of humidity and air movement, air temperature and radiation, and air temperature. It has been successfully used for environmental heat stress monitoring at military camps to control heat stress casualties. The measurements are few and easy to make; the instrumentation is simple, inexpensive, and rugged; and the calculations are straightforward. It is also the index used in the *ACGIH Threshold Limit Values* (TLVs®) *for Chemical Substances and Physical Agents and Biological Exposure Indices* (BEIs®) book (see Appendix B). The ACGIH recommends TLVs for continuous work in hot environments as well as when 25, 50, or 75 percent of each working hour is at rest. Regulating allowable exposure time in the heat is a viable technique for permitting necessary work to continue under heat-stress conditions that would be intolerable for continuous exposure. The NIOSH criteria document also contains a complete recommended heat stress control program including work practices.

Work practices include acclimation periods, work and rest regimens, distribution of work load with time, regular breaks of a minimum of one per hour, provision for water intake, protective clothing, and application of engineering controls. Experience has shown that workers do not stand a hot job very well at first, but develop tolerance rapidly through acclimation and acquire full endurance in a week to a month. (For more details, see Chapter 12, Thermal Stress, and the NIOSH criteria document.)

COLD STRESS

Generally, the answer to a cold work area is to supply heat where possible, except for areas that must be cold, such as food storage areas.

General hypothermia is an acute problem resulting from prolonged cold exposure and heat loss. If an individual becomes fatigued during physical activity, he or she will be more prone to heat loss, and as exhaustion approaches, sudden vasodilation (blood vessel dilation) occurs with resultant rapid loss of heat.

Cold stress is proportional to the total thermal gradient between the skin and the environment because this gradient determines the rate of heat loss from the body by radiation and convection. When vasoconstriction (blood vessel constriction) is no longer adequate to maintain body heat balance, shivering becomes an important mechanism for increasing body temperature by causing metabolic heat production to increase to several times the resting rate.

General physical activity increases metabolic heat. With clothing providing the proper insulation to minimize heat loss, a satisfactory microclimate can be maintained. Only exposed body surfaces are likely to be excessively chilled and frostbitten. If clothing becomes wet either from contact with water or due to sweating during intensive physical work, its cold-insulating property is greatly diminished.

Frostbite occurs when the skin tissues freeze. Theoretically, the freezing point of the skin is about 30 F (1 C); however, with increasing wind velocity, heat loss is greater and frostbite occurs more rapidly. Once started, freezing progresses rapidly. For example, if the wind velocity reaches 20 mph, exposed flesh can freeze within about 1 minute at 14 F (10 C). Furthermore, if the skin comes in direct contact with objects whose surface temperature is below the freezing point, frostbite can develop at the point of contact despite

warm environmental temperatures. Air movement is more important in cold environments than in hot because the combined effect of wind and temperature can produce a condition called *windchill*. The windchill index should be consulted by everyone facing exposure to low temperature and strong winds. (See Chapter 12, Thermal Stress.)

IONIZING RADIATION

A brief description of ionizing radiation hazards is given in this section; for a complete description, see Chapter 10, Ionizing Radiation.

To understand a little about ionization, recall that the human body is made up of various chemical compounds that are in turn composed of molecules and atoms. Each atom has a nucleus with its own outer system of electrons.

When ionization of body tissues occurs, some of the electrons surrounding the atoms are forcibly ejected from their orbits. The greater the intensity of the ionizing radiation, the more ions are created and the more physical damage is done to the cells.

Light consisting of electromagnetic radiation from the sun that strikes the surface of the earth is very similar to x-rays and gamma-radiation; it differs only in wavelength and energy content. (See description in Chapter 11, Nonionizing Radiation.) However, the energy level of sunlight at the earth's surface is too low to disturb orbital electrons, so sunlight is not considered ionizing even though it has enough energy to cause severe skin burns over a period of time.

The exact mechanism of the manner in which ionization affects body cells and tissue is complex. At the risk of oversimplifying some basic physical principles and ignoring others, the purpose of this section is to present enough information so the health and safety professional will recognize the problems involved and know when to call on health physicists or radiation safety experts for help.

At least three basic factors must be considered in such an approach to radiation safety:

- ➢ Radioactive materials emit energy that can damage living tissue.
- ➢ Different kinds of radioactivity present different kinds of radiation safety problems. The types of ionizing radiation we will consider are alpha-, beta-, x-ray, and gamma-radiation, and neutrons.
- ➢ Radioactive materials can be hazardous in two different ways. Certain materials can be hazardous even when located some distance away from the body; these are external hazards. Other types are hazardous only when they get inside the body through breathing, eating, or broken skin. These are called internal radiation hazards.

Instruments are available for evaluating possible radiation hazards. Meters or other devices are used for measuring radiation levels and doses.

Kinds of radioactivity. The five kinds of radioactivity that are of concern are alpha, beta, x-ray, gamma, and neutron. The first four are the most important because neutron sources usually are not used in ordinary manufacturing operations.

Of the five types of radiation mentioned, alpha-particles are the least penetrating. They do not penetrate thin barriers. For example, paper, cellophane, and skin stop alpha-particles.

Beta-radiation has considerably more penetrating power than alpha radiation. A quarter of an inch of aluminum can stop the more energetic betas. Virtually everyone is familiar with the penetrating ability of x rays and the fact that a barrier such as concrete or lead is required to stop them.

Gamma-rays are, for all practical purposes, the same as x rays and require the same kinds of heavy shielding materials.

Neutrons are very penetrating and have characteristics that make it necessary to use shielding materials of high hydrogen atom content rather than high mass alone.

Although the type of radiation from one radioactive material may be the same as that emitted by several other different radioactive materials, there may be a wide variation in energies.

The amount of energy a particular kind of radioactive material possesses is defined in terms of MeV (million electron volts); the greater the number of MeV, the greater the energy. Each radioactive material emits its own particular kinds of radiation, with energy measured in terms of MeV.

External versus internal hazards. Radioactive materials that emit x-rays, gamma-rays, or neutrons are external hazards. In other words, such materials can be located some distance from the body and emit radiation that produces ionization (and thus damage) as it passes through the body. Control by limiting exposure time, working at a safe distance, use of barriers or shielding, or a combination of all three is required for adequate protection against external radiation hazards.

As long as a radioactive material that emits only alpha-particles remains outside the body, it will not cause trouble. Internally, it is a hazard because the ionizing ability of alpha particles at very short distances in soft tissue makes them a veritable bulldozer. Once inside the body—in the lungs, stomach, or an open wound, for example—there is no thick layer of skin to serve as a barrier and damage results. Alpha-emitting radioactive materials that concentrate as persisting deposits in specific parts of the body are considered very hazardous.

Beta-emitters are generally considered an internal hazard although they also can be classed as an external hazard because they can produce burns when in contact with the skin. They require the same precautions as do alpha-emitters if there is a chance they can become airborne. In addition, some shielding may be required.

Measuring ionizing radiation. Many types of meters are used to measure various kinds of ionizing radiation. These

meters must be accurately calibrated for the type of radiation they are designed to measure.

Meters with very thin windows in the probes can be used to check for alpha-radiation. Geiger-Mueller and ionization chamber-type instruments are used for measuring beta-, gamma-, and x-radiation. Special types of meters are available for measuring neutrons.

Devices are available that measure accumulated amounts (doses) of radiation. Film badges are used as dosimeters to record the amount of radiation received from beta-, x-ray, or gamma-radiation and special badges are available to record neutron radiation.

Film badges are worn by a worker continuously during each monitoring period. Depending on how they are worn, they allow an estimate of an accumulated dose of radiation to the whole body or to just a part of the body, such as a hand or arm.

Alpha-radiation cannot be measured with film badges because alpha-particles do not penetrate the paper that must be used over the film emulsion to exclude light. (For more details on measurement and government regulations for ionizing radiation, see Chapter 10, Ionizing Radiation.)

NONIONIZING RADIATION

This is a form of electromagnetic radiation with varying effects on the body, depending largely on the wavelength of the radiation involved. In the following paragraphs, in approximate order of decreasing wavelength and increasing frequency, are some hazards associated with different regions of the nonionizing electromagnetic radiation spectrum. Nonionizing radiation is covered in detail by OSHAct regulations 29 *CFR* 1910.97, and in Chapter 11, Nonionizing Radiation.

Low frequency. Longer wavelengths, including powerline transmission frequencies, broadcast radio, and shortwave radio, can produce general heating of the body. The health hazard from these kinds of radiation is very small, however, because it is unlikely that they would be found in intensities great enough to cause significant effect. An exception can be found very close to powerful radio transmitter aerials.

Microwaves are found in radar, communications, some types of cooking, and diathermy applications. Microwave intensities may be sufficient to cause significant heating of tissues.

The effect is related to wavelength, power intensity, and time of exposure. Generally, longer wavelengths produce a greater penetration and temperature rise in deeper tissues than shorter wavelengths. However, for a given power intensity, there is less subjective awareness to the heat from longer wavelengths than there is to the heat from shorter wavelengths, because of the absorption of the longer wavelength radiation beneath the body's surface.

An intolerable rise in body temperature, as well as localized damage to specific organs, can result from an exposure of sufficient intensity and time. In addition, flammable gases and vapors can ignite when they are inside metallic objects located in a microwave beam.

Infrared radiation does not penetrate below the superficial layer of the skin, so its only effect is to heat the skin and the tissues immediately below it. Except for thermal burns, the health hazard of exposure to low-level conventional infrared radiation sources is negligible. (For information on possible damage to the eye, consult Chapter 11, Nonionizing Radiation.)

Visible radiation, which is about midway in the electromagnetic spectrum, is important because it can affect both the quality and accuracy of work. Good lighting conditions generally result in increased product quality with less spoilage and increased production.

Lighting should be bright enough for easy and efficient sight, and directed so that it does not create glare. Illumination levels and brightness ratios recommended for manufacturing and service industries are published by the Illuminating Engineering Society. (See Chapter 11, Nonionizing Radiation, for further information.)

One of the most objectionable features of lighting is glare (brightness in the field of vision that causes discomfort or interferes with seeing). The brightness can be caused by either direct or reflected light. To prevent glare, the source of light should be kept well above the line of vision or shielded with opaque or translucent material.

Almost as problematic is an area of excessively high brightness in the visual field. A highly reflective white paper in the center of a dark, nonreflecting surface or a brightly illuminated control handle on a dark or dirty machine are two examples.

To prevent such conditions, keep surfaces uniformly light or dark with little difference in surface reflectivity. Color contrasts are acceptable, however.

Although it is generally best to provide even, shadow-free light, some jobs require contrast lighting. In these cases, keep the general (or background) light well diffused and glareless and add a supplementary source of light that casts shadows where needed.

Ultraviolet radiation in industry can be found around electrical arcs, and such arcs should be shielded by materials opaque to ultraviolet. The fact that a material can be opaque to ultraviolet has no relation to its opacity to other parts of the spectrum. Ordinary window glass, for instance, is almost completely opaque to the ultraviolet in sunlight although transparent to the visible wavelengths. A piece of plastic dyed a deep red-violet may be almost entirely opaque in the visible part of the spectrum and transparent in the near-ultraviolet spectrum.

Electric welding arcs and germicidal lamps are the most common strong producers of ultraviolet radiation in industry. The ordinary fluorescent lamp generates a good deal of ultraviolet inside the bulb, but it is essentially all absorbed by the bulb and its coating.

The most common exposure to ultraviolet radiation is from direct sunlight, and a familiar result of overexposure—one that is known to all sunbathers—is sunburn. Most people are familiar with certain compounds and lotions that reduce the effects of the sun's rays, but many are unaware that some industrial materials, such as cresols, make the skin especially sensitive to ultraviolet rays. After exposure to cresols, even a short exposure in the sun usually results in a severe sunburn.

Lasers emit beams of coherent radiation of a single color or wavelength and frequency, in contrast to conventional light sources, which produce random, disordered light wave mixtures of various frequencies. The laser (an acronym for light amplification by stimulated emission of radiation) is made up of light waves that are nearly parallel to each other, all traveling in the same direction. Atoms are "pumped" full of energy, and when they are stimulated to fall to a lower energy level, they give off radiation that is directed to produce the coherent laser beam. (See Chapter 11, Nonionizing Radiation, for more details.)

The maser, the laser's predecessor, emits microwaves instead of light. Some companies call their lasers "optical masers." Because the laser is highly collimated (has a small divergence angle), it can have a large energy density in a narrow beam. Direct viewing of the laser source or its reflections should be avoided. The work area should contain no reflective surface (such as mirrors or highly polished furniture) because even a reflected laser beam can be hazardous. Suitable shielding to contain the laser beam should be provided. The OSHAct covers protection against laser hazards in its construction regulations.

Biological effects. The eye is the organ that is most vulnerable to injury by laser energy because the cornea and lens focus the parallel laser beam on a small spot on the retina. The fact that infrared radiation of certain lasers may not be visible to the naked eye contributes to the potential hazard.

Lasers generating in the ultraviolet range of the electromagnetic spectrum can produce corneal burns rather than retinal damage, because of the way the eye handles ultraviolet light. (See Chapter 11, Nonionizing Radiation.)

Other factors that affect the degree of eye injury induced by laser light are as follows:

- ➢ Pupil size (the smaller the pupil diameter, the less laser energy reaches the retina)
- ➢ The ability of the cornea and lens to focus the incident light on the retina
- ➢ The distance from the source of energy to the retina
- ➢ The energy and wavelength of the laser
- ➢ The pigmentation of the eye of the subject
- ➢ The location on the retina where the light is focused
- ➢ The divergence of the laser light
- ➢ The presence of scattering media in the light path

A discussion of laser beam characteristics and protective eyewear can be found in Chapter 11.

EXTREMES OF PRESSURE

It has been recognized from the beginning of caisson work (work performed in a watertight structure) that people working under pressures greater than normal atmospheric pressure are subject to various health effects. *Hyperbaric* (greater than normal pressure) environments are also encountered by divers who work under water, whether by holding the breath while diving, breathing from a self-contained underwater breathing apparatus (SCUBA), or by breathing gas mixtures supplied by compression from the surface.

Occupational exposures occur in caisson or tunneling operations, where a compressed gas environment is used to exclude water or mud and to provide support for structures. Humans can withstand large pressures if air has free access to lungs, sinuses, and the middle ear. Unequal distribution of pressure can result in barotrauma, a kind of tissue damage resulting from expansion or contraction of gas spaces within or adjacent to the body, which can occur either during compression (descent) or during decompression (ascent).

The teeth, sinuses, and ears are often affected by pressure differentials. For example, gas spaces adjacent to tooth roots or fillings may be compressed during descent. Fluid or tissue forced into these spaces can cause pain during descent or ascent. Sinus blockage caused by occlusion of the sinus aperture by inflamed nasal mucosa prevents equalization of pressures.

Under some conditions of work at high pressure, the concentration of carbon dioxide in the atmosphere can be considerably increased so that the carbon dioxide acts as a narcotic. Keeping the oxygen concentration high minimizes this condition, but does not prevent it. The procedure is useful where the carbon dioxide concentration cannot be kept at a proper level.

Decompression sickness, commonly called the bends, results from the release of nitrogen bubbles into the circulation and tissues during decompression. If the bubbles lodge at the joints and under muscles, they cause severe cramps. To prevent this, decompression is carried out slowly and by stages so that the nitrogen can be eliminated slowly, without forming bubbles.

Deep-sea divers are supplied with a mixture of helium and oxygen for breathing, and because helium is an inert diluent and less soluble in blood and tissue than is nitrogen, it presents a less formidable decompression problem.

One of the most common troubles encountered by workers under compressed air is pain and congestion in the ears from inability to ventilate the middle ear properly during compression and decompression. As a result, many workers subjected to increased air pressures suffer from temporary hearing loss; some have permanent hearing loss. This damage is believed to be caused by obstruction of the eustachian tubes, which prevents proper equalization of pressure from the throat to the middle ear.

The effects of reduced pressure on the worker are much the same as the effects of decompression from a high pressure. If

pressure is reduced too rapidly, decompression sickness and ear disturbances similar to the diver's conditions can result.

Ergonomic Hazards

Ergonomics literally means the study or measurement of work. It is the application of human biological science in conjunction with the engineering sciences to achieve the optimum mutual adjustment of people to their work, the benefits being measured in terms of human efficiency and well-being. The topic of ergonomics is covered briefly here. (For more details, see Chapter 13, Ergonomics.)

The ergonomics approach goes beyond productivity, health, and safety. It includes consideration of the total physiological and psychological demands of the job on the worker.

In the broad sense, the benefits that can be expected from designing work systems to minimize physical stress on workers are as follows:

- ➢ Reduced incidence of repetitive motion disorders
- ➢ Reduced injury rate
- ➢ More efficient operation
- ➢ Fewer accidents
- ➢ Lower cost of operation
- ➢ Reduced training time
- ➢ More effective use of personnel

The human body can endure considerable discomfort and stress and can perform many awkward and unnatural movements for a limited period of time. However, when awkward conditions or motions are continued for prolonged periods, they can exceed the worker's physiological limitations. To ensure a continued high level of performance, work systems must be tailored to human capacities and limitations.

Ergonomics considers the physiological and psychological stresses of the task. The task should not require excessive muscular effort, considering the worker's age, sex, and state of health. The job should not be so easy that boredom and inattention lead to unnecessary errors, material waste, and accidents. Ergonomic stresses can impair the health and efficiency of the worker just as significantly as the more commonly recognized environmental stresses.

The task of the design engineer and health and safety professional is to find the happy medium between "easy" and "difficult" jobs. In any human–machine system, there are tasks that are better performed by people than by machines and, conversely, tasks that are better handled by machines.

Ergonomics deals with the interactions between humans and such traditional environmental elements as atmospheric contaminants, heat, light, sound, and tools and equipment. People are the monitoring link of a human–machine environment system.

In any activity, a person receives and processes information, and then acts on it. The receptor function occurs largely through the sense organs of the eyes and the ear, but information can also be conveyed through the senses of smell, touch, or sensations of heat or cold. This information is conveyed to the central mechanism of the brain and spinal cord, where the information is processed to arrive at a decision. This can involve the integration of the information, which has already been stored in the brain, and decisions can vary from automatic responses to those involving a high degree of reasoning and logic.

Having received the information and processed it, the individual then takes action (control) as a result of the decision, usually through muscular activity based on the skeletal framework of the body. When an individual's activity involves the operation of a piece of equipment, the person often forms part of a "closed-loop servosystem," displaying many of the feedback characteristics of such a system. The person usually forms the part of the system that makes decisions, and thus has a fundamental part to play in the efficiency of the system.

BIOMECHANICS–PHYSICAL DEMANDS

Biomechanics can be a very effective tool in preventing excessive work stress. *Biomechanics* means the mechanics of biological organisms. It deals with the functioning of the structural elements of the body and the effects of external and internal forces on the various parts of the body.

Cumulative effects of excessive ergonomic stress on the worker can, in an insidious and subtle manner, result in physical illnesses and injuries such as "trigger finger," tenosynovitis, bursitis, carpal tunnel syndrome, and other cumulative trauma disorders.

Cases of excessive fatigue and discomfort are, in many cases, forerunners of soreness and pain. By exerting a strong distracting influence on a worker, these stresses can render the worker more prone to major accidents. Discomfort and fatigue tend to make the worker less capable of maintaining the proper vigilance for the safe performance of the task.

Some of the principles of biomechanics can be illustrated by considering different parts of the human anatomy, such as the hand.

Hand anatomy. The flexing action in the fingers is controlled by tendons attached to muscles in the forearm. The tendons, which run in lubricated sheaths, enter the hand through a tunnel in the wrist formed by bones and ligaments (the carpal tunnel) and continue on to point of attachment to the different segments, or phalanges, of the fingers (Figure 1–3).

When the wrist is bent toward the little finger side, the tendons tend to bunch up on one side of the tunnel through which they enter the hand. If an excessive amount of force is continuously applied with the fingers while the wrist is flexed, or if the flexing motion is repeated rapidly over a long period of time, the resulting friction can produce inflammation of the tendon sheaths, or tenosynovitis. This can lead to a disabling condition called carpal tunnel syndrome. (See Chapter 13, Ergonomics.)

The palm of the hand, which contains a network of nerves and blood vessels, should never be used as a hammer or

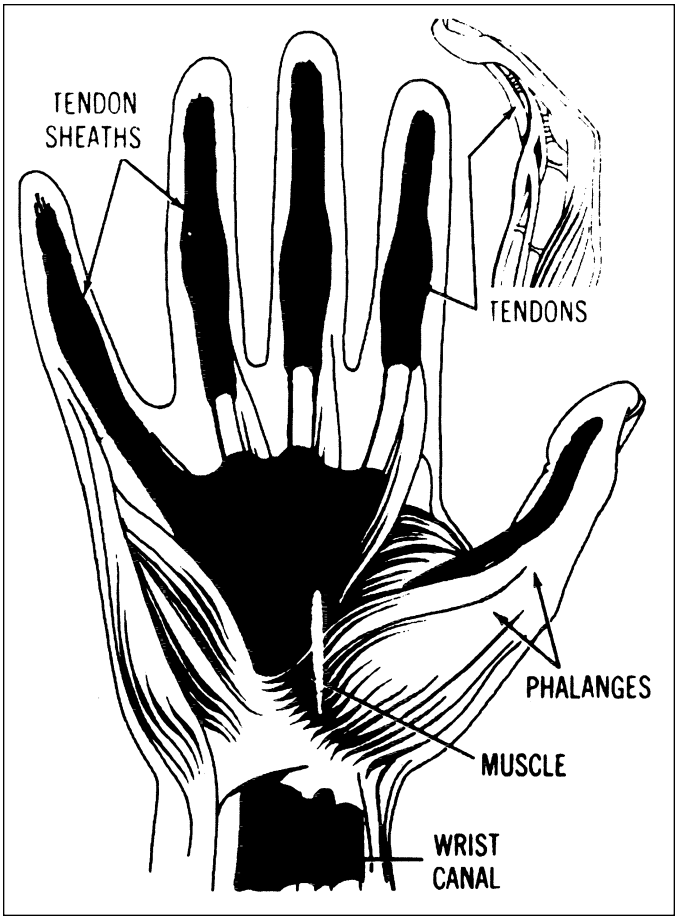

Figure 1–3. Diagram of hand anatomy.

subjected to continued firm pressure. Repetitive or prolonged pressure on the nerves and blood vessels in this area can result in pain either in the palm itself or at any point along the nerve pathways up through the arm and shoulder. Other parts of the body, such as the elbow joints and shoulders, can become painful for similar reasons.

Mechanical vibration. A condition known to stonecutters as "dead fingers" or "white fingers" (Raynaud's phenomenon) occurs mainly in the fingers of the hand used to guide the cutting tool. The circulation in this hand becomes impaired, and when exposed to cold the fingers become white and without sensation, as though mildly frostbitten. The white appearance usually disappears when the fingers are warmed for some time, but a few cases are sufficiently disabling that the victims are forced to seek other types of work. In many instances both hands are affected.

The condition has been observed in a number of other occupations involving the use of vibrating tools, such as the air hammers used for scarfing metal surfaces, the air chisels for chipping castings in the metal trades, and the chain saws used in forestry. The injury is caused by vibration of the fingers as they grip the tools to guide them in performing their tasks. The related damage to blood vessels can progress to nearly complete obstruction of the vessels.

Prevention should be directed at reducing the vibrational energy transferred to the fingers (perhaps by the use of padding) and by changing the energy and frequency of the vibration. Low frequencies, 25–75 hertz, are more damaging than higher frequencies.

Lifting. The injuries resulting from manual handling of objects and materials make up a large proportion of all compensable injuries. This problem is of considerable concern to the health and safety professional and represents an area where the biomechanical data relating to lifting and carrying can be applied in the work layout and design of jobs that require handling of materials. (For more details, see Chapter 13, Ergonomics, and the *Application Manual for the Revised NIOSH Lifting Equation*.)

The relevant data concerning lifting can be classified into task, human, and environmental variables.

➢ *Task variables*
- Location of object to be lifted
- Size of the object to be lifted
- Height from which and to which the object is lifted
- Frequency of lift
- Weight of object
- Working position

➢ *Human variables*
- Sex of worker
- Age of worker
- Training of worker
- Physical fitness or conditioning of worker
- Body dimensions, such as height of the worker

➢ *Environmental variables*
- Extremes of temperature
- Humidity
- Air contaminants

Static work. Another very fatiguing situation encountered in industry, which unfortunately is often overlooked, is static, or isometric, work. Because very little outward movement occurs, it seems that no muscular effort is involved. Often, however, such work generates more muscular fatigue than work involving some outward movement. A cramped working posture, for example, is a substantial source of static muscular loading.

In general, maintaining any set of muscles in a rigid, unsupported position for long periods of time results in muscular strain. The blood supply to the contracted muscle is diminished, a local deficiency of oxygen can occur, and waste products accumulate. Alternating static and dynamic work, or providing support for partial relaxation of the member involved, alleviates this problem.

Armrests are usually needed in two types of situations. One is the case just mentioned—to relieve the isometric muscular work involved in holding the arm in a fixed, unsupported

position for long periods of time. The second case is where the arm is pressed against a hard surface such as the edge of a bench or machine. The pressure on the soft tissues overlaying the bones can cause bruises and pain. Padded armrests have solved numerous problems of both types (see Figure 1–4).

WORKPLACE DESIGN

Relating the physical characteristics and capabilities of the worker to the design of equipment and to the layout of the workplace is another key ergonomic concept. When this is done, the result is an increase in efficiency, a decrease in human error, and a consequent reduction in accident frequency. However, several different types of information are needed: a description of the job, an understanding of the kinds of equipment to be used, a description of the kinds of people who will use the equipment, and the biological characteristics of these people.

In general, the first three items—job, equipment, and users—can be defined easily. The biological characteristics of the users, however, can often be determined satisfactorily only from special surveys that yield descriptive data on human body size and biomechanical abilities and limitations.

Anthropometric data. Anthropometric data consist of various heights, lengths, and breadths used to establish the minimum clearances and spatial accommodations, and the functional arm, leg, and body movements that are made by the worker during the performance of the task.

BEHAVIORAL ASPECTS—MENTAL DEMANDS

One important aspect of industrial machine design directly related to the safety and productivity of the worker is the design of displays and controls.

Design of displays. Displays are one of the most common types of operator input; the others include direct sensing and verbal or visual commands. Displays tell the operator what the machine is doing and how it is performing. Problems of display design are primarily related to the human senses.

A machine operator can successfully control equipment only to the extent that the operator receives clear, unambiguous information, when needed on all pertinent aspects of the task. Accidents, or operational errors, often occur because a worker has misinterpreted or was unable to obtain information from displays. Displays are usually visual, although they also can be auditory (for example, a warning bell rather than a warning light), especially when there is danger of overloading the visual sensory channels.

Design of Controls. An operator must decide on the proper course of action and manipulate controls to produce any desired change in the machine's performance. The efficiency and effectiveness—that is, the safety with which controls can be operated—depend on the extent to which information on the dynamics of human movement (or biomechanics) has been incorporated in their design. This is particularly true whenever controls must be operated at high speed, against large resistances, with great precision, or over long periods of time.

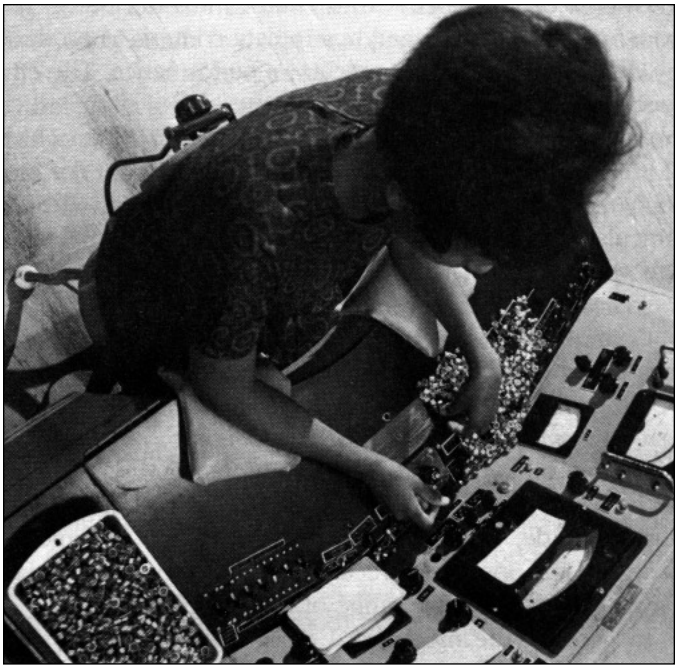

Figure 1–4. Worker uses pads to keep her forearm off the sharp table edge.

Controls should be designed so that rapid, accurate settings easily can be made without undue fatigue, thereby avoiding many accidents and operational errors. Because there is a wide variety of machine controls, ranging from the simple on–off action of pushbuttons to very complex mechanisms, advance analysis of the task requirements must be made. On the basis of considerable experimental evidence, it is possible to recommend the most appropriate control and its desirable range of operation.

In general, the mechanical design of equipment must be compatible with the biological and psychological characteristics of the operator. The effectiveness of the human–machine combination can be greatly enhanced by treating the operator and the equipment as a unified system. Thus, the instruments should be considered as extensions of the operator's nervous and perceptual systems, the controls as extensions of the hands, and the feet as simple tools. Any control that is difficult to reach or operate, any instrument dial that has poor legibility, any seat that induces poor posture or discomfort, or any obstruction of vision can contribute directly to an accident or illness.

Biological Hazards

Approximately 200 biological agents, such as infectious microorganisms, biological allergens, and toxins, are known to produce infections or allergenic, toxic, or carcinogenic reactions in workers. Most of the identified biohazardous agents belong to these groups:

- ➢ Microorganisms and their toxins (viruses, bacteria, fungi, and their products) resulting in infection, exposure, or allergy
- ➢ Arthropods (crustaceans, arachnids, insects) associated with bites or stings resulting in skin inflammation, systemic intoxication and transmission of infectious agents, or allergic response
- ➢ Allergens and toxins from higher plants, producing dermatitis, rhinitis, or asthma
- ➢ Protein allergens (such as urine, feces, hair, saliva, and dander) from vertebrate animals

Other groups with the potential to expose workers to biohazards include lower plants other than fungi (lichen, liverworts, ferns) and invertebrate animals other than arthropods (parasites such as protozoa, *Schistosoma*) and roundworms (*Ascaris*).

Workers engaging in agricultural, medical, and laboratory work have been identified as most at risk to occupational biohazards but many varied workplaces present the potential for such exposure. For example, at least 24 of the 150 zoonotic diseases known worldwide are considered to be a hazard for agricultural workers in North America. Risk of infection varies with the type and species of animal and geographic location. Disease may be contracted directly from animals, but more often it is acquired in the workplace environment. Controls include awareness of specific hazards, use of personal protective equipment, preventive veterinary care, worker education, and medical monitoring or prophylactic therapy, where appropriate.

The potential for exposure to occupational biohazards exists in most work environments. The following are but a few examples in very diverse workplaces:

- ➢ Workers maintaining water systems can be exposed to *Legionella pneumophila* and *Naegleria spp.*
- ➢ Workers associated with birds (parrots, parakeets, pigeons) in pet shops, aviaries, or on construction and public works jobs near perching or nesting sites can be exposed to *Chlamydia psittaci.*
- ➢ Workers in wood processing facilities can be exposed to endotoxins, allergenic fungi growing on timber, and fungi causing deep mycoses.
- ➢ Sewage and compost workers can be exposed to enteric bacteria, hepatitis A virus, infectious or endotoxin-producing bacteria, parasitic protozoa, and allergenic fungi.
- ➢ Health care workers, emergency responders, law enforcement officers, and morticians may be exposed to such bloodborne pathogens as hepatitis B (HBV), hepatitis C (HCV), and the human immunodeficiency virus (HIV) in addition to other biological hazards. (See Chapter 14, Biological Hazards.)

BUILDING-RELATED ILLNESSES DUE TO BIOLOGICAL HAZARDS

The sources of biological hazards may be fairly obvious in occupations associated with the handling of microorganisms, plants, and animals and in occupations involving contact with potentially infected people. However, recognizing and identifying biological hazards may not be as simple in other situations such as office buildings and nonindustrial workplaces. Building-related illness (BRI) is a clinically diagnosed disease in one or more building occupants, as distinguished from sick-building syndrome (SBS), in which building occupants' nonspecific symptoms cannot be associated with an identifiable cause. Certain BRI such as infectious and hypersensitivity diseases are clearly associated with biological hazards, but the role of biological materials in SBS is not as well understood.

The conditions and events necessary to result in human exposure to bioaerosols are the presence of a reservoir that can support the growth of microorganisms or allow accumulation of biological material, multiplication of contaminating organisms or biological materials in the reservoir, generation of aerosols containing biological material, and exposure of susceptible workers. (See Chapter 14, Biological Hazards, for a full discussion.)

INDUSTRIAL SANITATION—WATER SUPPLY

The requirements for sanitation and personal facilities are covered in the OSHAct safety and health regulations 29 *CFR* 1910, Subpart J—General Environmental Controls. The OSHAct regulations for carcinogens require special personal health and sanitary facilities for employees working with potentially carcinogenic materials.

Potable water should be provided in workplaces when needed for drinking and personal washing, cooking, washing of foods or utensils, washing of food preparation premises, and personal service rooms.

Drinking fountain surfaces must be constructed of materials impervious to water and not subject to oxidation. The nozzle of the fountain must be located to prevent the return of water in the jet or bowl to the nozzle orifice. A guard over the nozzle prevents contact with the nozzle by the mouth or nose of people using the drinking fountain.

Potable drinking water dispensers must be designed and constructed so that sanitary conditions are maintained; they must be capable of being closed and equipped with a tap. Ice that comes in contact with drinking water must be made of potable water and maintained in a sanitary condition. Standing water in cooling towers and other air-moving systems should be monitored for legionella bacteria. (See Chapter 14, Biological Hazards, for details.)

Outlets for nonpotable water, such as water for industrial or firefighting purposes, must be marked in a manner that indicates clearly that the water is unsafe and is not to be used as drinking water. Nonpotable water systems or systems carrying any other nonpotable substance should be constructed so as to prevent backflow or backsiphonage.

HARMFUL AGENTS–ROUTE OF ENTRY

In order to exert its toxic effect, a harmful agent must come into contact with a body cell and must enter the body via inhalation, skin absorption, or ingestion.

Chemical compounds in the form of liquids, gases, mists, dusts, fumes, and vapors can cause problems by inhalation (breathing), absorption (through direct contact with the skin), or ingestion (eating or drinking).

Inhalation

Inhalation involves airborne contaminants that can be inhaled directly into the lungs and can be physically classified as gases, vapors, and particulate matter including dusts, fumes, smokes, aerosols, and mists.

Inhalation, as a route of entry, is particularly important because of the rapidity with which a toxic material can be absorbed in the lungs, pass into the bloodstream, and reach the brain. Inhalation is the major route of entry for hazardous chemicals in the work environment.

Absorption

Absorption through the skin can occur quite rapidly if the skin is cut or abraded. Intact skin, however, offers a reasonably good barrier to chemicals. Unfortunately, there are many compounds that can be absorbed through intact skin.

Some substances are absorbed by way of the openings for hair follicles and others dissolve in the fats and oils of the skin, such as organic lead compounds, many nitro compounds, and organic phosphate pesticides. Compounds that are good solvents for fats (such as toluene and xylene) also can be absorbed through the skin.

Many organic compounds, such as TNT, cyanides, and most aromatic amines, amides, and phenols, can produce systemic poisoning by direct contact with the skin.

Ingestion

In the workplace, people can unknowingly eat or drink harmful chemicals. Toxic compounds can be absorbed from the gastrointestinal tract into the blood. Lead oxide can cause serious problems if people working with this material are allowed to eat or smoke in work areas. Thorough washing is required both before eating and at the end of every shift.

Inhaled toxic dusts can also be ingested in hazardous amounts. If the toxic dust swallowed with food or saliva is not soluble in digestive fluids, it is eliminated directly through the intestinal tract. Toxic materials that are readily soluble in digestive fluids can be absorbed into the blood from the digestive system.

It is important to study all routes of entry when evaluating the work environment—candy bars or lunches in the work area, solvents being used to clean work clothing and hands, in addition to airborne contaminants in working areas. (For more details, see Chapter 6, Industrial Toxicology.)

TYPES OF AIRBORNE CONTAMINANTS

There are precise meanings of certain words commonly used in industrial hygiene. These must be used correctly in order to understand the requirements of OSHAct regulations, effectively communicate with other occupational health professionals, recommend or design and test appropriate engineering controls, and correctly prescribe personal protective equipment. For example, a fume respirator is worthless as protection against gases or vapors. Too often, terms (such as gases, vapors, fumes, and mists) are used interchangeably. Each term has a definite meaning and describes a certain state of matter.

States of Matter

Matter is divided into dusts, fumes, smoke, aerosols, mists, gases, and vapors. These are discussed in the following sections.

DUSTS

These are solid particles generated by handling, crushing, grinding, rapid impact, detonation, and decrepitation (breaking apart by heating) of organic or inorganic materials, such as rock, ore, metal, coal, wood, and grain.

Dust is a term used in industry to describe airborne solid particles that range in size from 0.1–25 μm in diameter (1 μm = 0.0001 cm or 1/25,400 in.). Dusts more than 5 μm in size usually do not remain airborne long enough to present an inhalation problem (see Chapter 8, Particulates).

Dust can enter the air from various sources, such as when a dusty material is handled (as when lead oxide is dumped into a mixer or talc is dusted on a product). When solid materials are reduced to small sizes in processes such as grinding, crushing, blasting, shaking, and drilling, the mechanical action of the grinding or shaking device supplies energy to disperse the dust.

Evaluating dust exposures properly requires knowledge of the chemical composition, particle size, dust concentration in air, how it is dispersed, and many other factors described here. Although in the case of gases, the concentration that reaches the alveolar sacs is nearly like the concentration in the air breathed, this is not the case for aerosols or dust particles. Large particles, more than 10 μm aerodynamic diameter, can be deposited through gravity and impaction in large ducts before they reach the very small sacs (alveoli). Only the smaller particles reach the alveoli. (See Chapter 2, The Lungs, for more details.)

Except for some fibrous materials, dust particles must usually be smaller than 5 μm in order to penetrate to the alveoli or inner recess of the lungs.

A person with normal eyesight can detect dust particles as small as 50 μm in diameter. Smaller airborne particles can be detected individually by the naked eye only when strong light is reflected from them. Particles of dust of respirable size (less than 10 μm) cannot be seen without the aid of a microscope, but they may be perceived as a haze.

Most industrial dusts consist of particles that vary widely in size, with the small particles greatly outnumbering the large ones. Consequently (with few exceptions), when dust is noticeable in the air near a dusty operation, probably more invisible dust particles than visible ones are present. A

process that produces dust fine enough to remain suspended in the air long enough to be breathed should be regarded as hazardous until it can be proved safe.

There is no simple one-to-one relationship between the concentration of an atmospheric contaminant and duration of exposure and the rate of dosage by the hazardous agent to the critical site in the body. For a given magnitude of atmospheric exposure to a potentially toxic particulate contaminant, the resulting hazard can range from an insignificant level to one of great danger, depending on the toxicity of the material, the size of the inhaled particles, and other factors that determine their fate in the respiratory system.

FUMES

These are formed when the material from a volatilized solid condenses in cool air. The solid particles that are formed make up a fume that is extremely fine, usually less than 1.0 μm in diameter. In most cases, the hot vapor reacts with the air to form an oxide. Gases and vapors are not fumes, although the terms are often mistakenly used interchangeably.

Welding, metalizing, and other operations involving vapors from molten metals may produce fumes; these may be harmful under certain conditions. Arc welding volatilizes metal vapor that condenses as the metal or its oxide in the air around the arc. In addition, the rod coating is partially volatilized. These fumes, because they are extremely fine, are readily inhaled.

Other toxic fumes, such as those formed when welding structures that have been painted with lead-based paints or when welding galvanized metal, can produce severe symptoms of toxicity rather rapidly unless fumes are controlled with effective local exhaust ventilation or the welder is protected by respiratory protective equipment.

Fortunately, most soldering operations do not require temperatures high enough to volatilize an appreciable amount of lead. However, the lead in molten solder pots is oxidized by contact with air at the surface. If this oxide, often called dross, is mechanically dispersed into the air, it can produce a severe lead-poisoning hazard.

In operations when lead dust may be present in air, such as soldering or lead battery-making, preventing occupational poisoning is largely a matter of scrupulously clean housekeeping to prevent the lead oxide from becoming dispersed into the air. It is customary to enclose melting pots, dross boxes, and similar operations, and to ventilate them adequately to control the hazard. Other controls may be necessary as well.

SMOKE

This consists of carbon or soot particles less than 0.1 μm in size, and results from the incomplete combustion of carbonaceous materials such as coal or oil. Smoke generally contains droplets as well as dry particles. Tobacco, for instance, produces a wet smoke composed of minute tarry droplets.

AEROSOLS

These are liquid droplets or solid particles of fine enough particle size to remain dispersed in air for a prolonged period of time.

MISTS

These are suspended liquid droplets generated by condensation of liquids from the vapor back to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, or atomizing. The term *mist* is applied to a finely divided liquid suspended in the atmosphere. Examples are the oil mist produced during cutting and grinding operations, acid mists from electroplating, acid or alkali mists from pickling operations, paint spray mist in painting operations, and the condensation of water vapor to form a fog or rain.

GASES

These are formless fluids that expand to occupy the space or enclosure in which they are confined. Gases are a state of matter in which the molecules are unrestricted by cohesive forces. Examples are arc-welding gases, internal combustion engine exhaust gases, and air.

VAPORS

These are the volatile form of substances that are normally in the solid or liquid state at room temperature and pressure. Evaporation is the process by which a liquid is changed into the vapor state and mixed with the surrounding atmosphere. Solvents with low boiling points volatilize readily at room temperature.

In addition to the definitions concerning states of matter that are used daily by industrial hygienists, terms used to describe degree of exposure include the following:

- ppm: parts of vapor or gases per million parts of air by volume at room temperature and pressure
- mppcf: millions of particles of a particulate per cubic foot of air
- mg/m^3: milligrams of a substance per cubic meter of air
- f/cc: fibers of a substance per cubic centimeter of air

The health and safety professional recognizes that air contaminants exist as a gas, dust, fume, mist, or vapor in the workroom air. In evaluating the degree of exposure, the measured concentration of the air contaminant is compared to limits or exposure guidelines that appear in the published standards on levels of exposure (see Appendix B).

Respiratory Hazards

Airborne chemical agents that enter the lungs can pass directly into the bloodstream and be carried to other parts of the body. The respiratory system consists of organs contributing to normal respiration or breathing. Strictly speaking, it includes the nose, mouth, upper throat, larynx, trachea, and bronchi (which are all air passages or airways) and the lungs, where oxygen is passed into the blood and carbon dioxide is given off. Finally, it includes the

diaphragm and the muscles of the chest, which perform the normal respiratory movements of inspiration and expiration. (See Chapter 2, The Lungs.)

All living cells of the body are engaged in a series of chemical processes; the sum total of these processes is called metabolism. In the course of its metabolism, each cell consumes oxygen and produces carbon dioxide as a waste product.

Respiratory hazards can be broken down into two main groups:

- ➢ Oxygen deficiency, in which the oxygen concentration (or partial pressure of oxygen) is below the level considered safe for human exposure
- ➢ Air that contains harmful or toxic contaminants

OXYGEN-DEFICIENT ATMOSPHERES

Each living cell in the body requires a constant supply of oxygen. Some cells are more dependent on a continuing oxygen supply than others. Some cells in the brain and nervous system can be injured or die after 4–6 min without oxygen. These cells, if destroyed, cannot be regenerated or replaced, and permanent changes and impaired functioning of the brain can result from such damage. Other cells in the body are not as critically dependent on an oxygen supply because they can be replaced.

Normal air at sea level contains approximately 21 percent oxygen and 79 percent nitrogen and other inert gases. At sea level and normal barometric pressure (760 mmHg or 101.3 kPa), the partial pressure of oxygen would be 21 percent of 760 mm, or 160 mm. The partial pressure of nitrogen and inert gases would be 600 mm (79 percent of 760 mm).

At higher altitudes or under conditions of reduced barometric pressure, the relative proportions of oxygen and nitrogen remain the same, but the partial pressure of each gas is decreased. The partial pressure of oxygen at the alveolar surface of the lung is critical because it determines the rate of oxygen diffusion through the moist lung tissue membranes.

Oxygen-deficient atmospheres may exist in confined spaces as oxygen is *consumed* by chemical reactions such as oxidation (rust, fermentation), *replaced* by inert gases such as argon, nitrogen, and carbon dioxide, or *absorbed* by porous surfaces such as activated charcoal.

Deficiency of oxygen in the atmosphere of confined spaces can be a problem in industry. For this reason, the oxygen content of any tank or other confined space (as well as the levels of any toxic contaminants) should be measured before entry is made. Instruments are commercially available for this purpose. (See Chapter 16, Air Sampling, Chapter 17, Direct-Reading Instruments for Gases, Vapors, and Particulates, and Chapter 22, Respiratory Protection, for more details.)

The first physiological signs of an oxygen deficiency (anoxia) are an increased rate and depth of breathing. A worker should never enter or remain in areas where tests have indicated oxygen deficiency without a supplied-air or self-contained respirator that is specifically approved by NIOSH for those conditions. (See Chapter 22, Respiratory Protection, for more details.)

Oxygen-deficient atmospheres can cause an inability to move and a semiconscious lack of concern about the imminence of death. In cases of abrupt entry into areas containing little or no oxygen, the person usually has no warning symptoms, immediately loses consciousness, and has no recollection of the incident if rescued in time to be revived. The senses cannot be relied on to alert or warn a person of atmospheres deficient in oxygen.

Oxygen-deficient atmospheres can occur in tanks, vats, holds of ships, silos, mines, or in areas where the air may be diluted or displaced by asphyxiating levels of gases or vapors, or where the oxygen may have been consumed by chemical or biological reactions.

Ordinary jobs involving maintenance and repair of systems for storing and transporting fluids or entering tanks or tunnels for cleaning and repairs are controlled almost entirely by the immediate supervisor. The supervisor should be particularly knowledgeable of all rules and precautions to ensure the safety of those who work in such atmospheres. Safeguards should be meticulously observed.

For example, there should be a standard operating procedure for entering tanks. Such procedures should be consistent with OSHAct regulations and augmented by in-house procedures, which may enhance the basic OSHAct rules. The American National Standards Institute (ANSI) lists confined space procedures in its respiratory protection standard and NIOSH has also issued guidelines for work in confined spaces including a criteria document for working in confined spaces (see Bibliography). Even if a tank is empty, it may have been closed for some time and developed an oxygen deficiency through chemical reactions of residues left in the tank. It may be unsafe to enter without proper respiratory protection.

THE HAZARD OF AIRBORNE CONTAMINANTS

Inhaling harmful materials can irritate the upper respiratory tract and lung tissue, or the terminal passages of the lungs and the air sacs, depending on the solubility of the material.

Inhalation of biologically inert gases can dilute the atmospheric oxygen below the normal blood saturation value and disturb cellular processes. Other gases and vapors may prevent the blood from carrying oxygen to the tissues or interfere with its transfer from the blood to the tissue, producing chemical asphyxia.

Inhaled contaminants that adversely affect the lungs fall into three general categories:

- ➢ Aerosols (particulates), which, when deposited in the lungs, can produce either rapid local tissue damage, some slower tissue reactions, eventual disease, or physical plugging
- ➢ Toxic vapors and gases that produce adverse reaction in the tissue of the lungs

➢ Some toxic aerosols or gases that do not affect the lung tissue locally but pass from the lungs into the bloodstream, where they are carried to other body organs or have adverse effects on the oxygen-carrying capacity of the blood cells

An example of an aerosol is silica dust, which causes fibrotic growth (scar tissue) in the lungs. Other harmful aerosols are fungi found in sugar cane residues, producing bagassosis.

An example of the second type of inhaled contaminant is hydrogen fluoride, a gas that directly affects lung tissue. It is a primary irritant of mucous membranes, even causing chemical burns. Inhalation of this gas causes pulmonary edema and direct interference with the gas transfer function of the alveolar lining.

An example of the third type of inhaled contaminant is carbon monoxide, a toxic gas passed into the bloodstream without harming the lung. The carbon monoxide passes through the alveolar walls into the blood, where it ties up the hemoglobin so that it cannot accept oxygen, thus causing oxygen starvation. Cyanide gas has another effect—it prevents enzymatic utilization of molecular oxygen by cells.

Sometimes several types of lung hazards occur simultaneously. In mining operations, for example, explosives release oxides of nitrogen. These impair the bronchial clearance mechanism so that coal dust (of the particle sizes associated with the explosions) is not efficiently cleansed from the lungs.

If a compound is very soluble—such as ammonia, sulfuric acid, or hydrochloric acid—it is rapidly absorbed in the upper respiratory tract and during the initial phases of exposure does not penetrate deeply into the lungs. Consequently, the nose and throat become very irritated.

Compounds that are insoluble in body fluids cause considerably less throat irritation than the soluble ones, but can penetrate deeply into the lungs. Thus, a very serious hazard can be present and not be recognized immediately because of a lack of warning that the local irritation would otherwise provide. Examples of such compounds (gases) are nitrogen dioxide and ozone. The immediate danger from these compounds in high concentrations is acute lung irritation or, possibly, chemical pneumonia.

There are numerous chemical compounds that do not follow the general solubility rule. Such compounds are not very soluble in water and yet are very irritating to the eyes and respiratory tract. They also can cause lung damage and even death under certain conditions. (See Chapter 6, Industrial Toxicology.)

THRESHOLD LIMIT VALUES

The ACGIH Threshold Limit Values® (TLVs®) are exposure guidelines established for airborne concentrations of many chemical compounds. The health and safety professional or other responsible person should understand something about TLVs and the terminology in which their concentrations are expressed. (See Chapter 15, Evaluation, Chapter 6, Industrial Toxicology, and Appendix B for more details.)

TLVs are airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect. Control of the work environment is based on the assumption that for each substance there is some safe or tolerable level of exposure below which no significant adverse effect occurs. These tolerable levels are called Threshold Limit Values. In its Introduction, the ACGIH *Threshold Limit Values* (*TLVs®*) *for Chemical Subtances and Physical Agents and Biological Exposure Indices* (*BEIs®*) states that because individual susceptibility varies widely, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit. A smaller percentage may be affected more seriously by aggravation of a preexisting condition or by development of an occupational illness. Smoking may enhance the biological effects of chemicals encountered in the workplace and may reduce the body's defense mechanisms against toxic substances.

Hypersusceptible individuals or those otherwise unusually responsive to some industrial chemicals because of genetic factors, age, personal habits (smoking and use of alcohol or other drugs), medication, or previous exposures may not be adequately protected from adverse health effects of chemicals at concentrations at or below the threshold limits.

These limits are not fine lines between safe and dangerous concentration, nor are they a relative index of toxicity. They should not be used by anyone untrained in the discipline of industrial hygiene.

The copyrighted trademark *Threshold Limit Value®* refers to limits published by ACGIH. The TLVs are reviewed and updated annually to reflect the most current information on the effects of each substance assigned a TLV. (See Appendix B and the Bibliography of this chapter.)

The data for establishing TLVs come from animal studies, human studies, and industrial experience, and the limit may be selected for several reasons. As mentioned earlier in this chapter, the TLV can be based on the fact that a substance is very irritating to the majority of people exposed, or the fact that a substance is an asphyxiant. Still other reasons for establishing a TLV for a given substance include the fact that certain chemical compounds are anesthetic or fibrogenic or can cause allergic reactions or malignancies. Some additional TLVs have been established because exposure above a certain airborne concentration is a nuisance.

The amount and nature of the information available for establishing a TLV varies from substance to substance; consequently, the precision of the estimated TLV continues to be subject to revision and debate. The latest documentation for that substance should be consulted to assess the present data available for a given substance.

In addition to the TLVs set for chemical compounds, there are limits for physical agents such as noise,

radiofrequency/microwave radiation, segmental vibration, lasers, ionizing radiation, static magnetic fields, light, near-infrared radiation, subradiofrequency (≤ 30 kHz) magnetic fields, subradiofrequency and static electric fields, ultraviolet radiation, cold stress, and heat stress. There are also biological exposure indices (BEIs®). (See Chapter 9, Industrial Noise, Chapter 11, Nonionizing Radiation, and Appendix B.)

The ACGIH periodically publishes a documentation of TLVs® in which it gives the data and information on which the TLV for each substance is based. This documentation can be used to provide health and safety professionals with insight to aid professional judgment when applying the TLVs.

The most current edition of the ACGIH *Threshold Limit Values* (*TLVs®*) *for Chemical Substances and Physical Agents and Biological Exposure Indices* (*BEIs®*) should be used. When referring to an ACGIH TLV, the year of publication should always preface the value, as in "the 2001 TLV for nitric oxide was 25 ppm." Note that the TLVs are not mandatory federal or state employee exposure standards, and the term *TLV* should not be used for standards published by OSHA or any agency except the ACGIH.

Three categories of Threshold Limit Values are specified as follows:

TIME-WEIGHTED AVERAGE (TLV–TWA)

This is the time-weighted average concentration for a conventional eight-hour workday and 40-hour workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect.

SHORT-TERM EXPOSURE LIMIT (TLV–STEL)

This is the concentration to which it is believed workers can be exposed continuously for a short period of time without suffering from:

- Irritation
- Chronic or irreversible tissue damage
- Narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue, or materially reduce work efficiency and provided that the daily TLV–TWA is not exceeded

A STEL is a 15-min TWA exposure that should not be exceeded at any time during a workday, even if the eight-hour TWA is within the TLV-TWA. Exposures above the TLV-TWA up to the STEL should not be longer than 15 min and should not occur more than four times per day. There should be at least 60 min between successive exposures in this range.

The TLV–STEL is not a separate, independent exposure limit; it supplements the TWA limit when there are recognized acute effects from a substance that has primarily chronic effects. The STELs are recommended only when toxic effects in humans or animals have been reported from high short-term exposures.

Note: None of the limits mentioned here, especially the TWA–STEL, should be used as engineering design criteria.

CEILING (TLV–C)

This is the concentration that should not be exceeded during any part of the working exposure. To assess a TLV–C if instantaneous monitoring is not feasible, the conventional industrial hygiene practice is to sample during a 15-min period, except for substances that can cause immediate irritation with short exposures.

For some substances (such as irritant gases), only one category, the TLV–C, may be relevant. For other substances, two or three categories may be relevant, depending on their physiological action. If any one of these three TLVs is exceeded, a potential hazard from that substance is presumed to exist.

Limits based on physical irritation should be considered no less binding than those based on physical impairment. Increasing evidence shows that physical irritation can initiate, promote, or accelerate physical impairment via interaction with other chemical or biological agents.

The amount by which threshold limits can be exceeded for short periods without injury to health depends on many factors: the nature of the contaminant; whether very high concentrations, even for a short period, produce acute poisoning; whether the effects are cumulative; the frequency with which high concentrations occur; and the duration of such periods. All factors must be considered when deciding whether a hazardous condition exists.

Skin Notation

A number of the substances in the TLV list are followed by the designation *Skin*. This refers to potential significant exposure through the cutaneous route, including mucous membranes and the eyes, either by contact with vapors or, of probably greater significance, by direct skin contact with the substance. Vehicles such as certain solvents can alter skin absorption. This designation is intended to suggest appropriate measures for the prevention of cutaneous absorption.

Mixtures

Special consideration should be given in assessing the health hazards that can be associated with exposure to mixtures of two or more substances.

Federal Occupational Safety and Health Standards

The first compilation of the health and safety standards promulgated by OSHA in 1970 was derived from the then-existing federal standards and national consensus standards. Thus, many of the 1968 TLVs established by the ACGIH became federal standards or permissible exposure limits (PELs). Also, certain workplace quality standards known as ANSI maximal acceptable concentrations were incorporated as federal health standards in 29 *CFR* 1910.1000 (Table Z–2) as national consensus standards.

In adopting the ACGIH TLVs, OSHA also adopted the concept of the TWA for a workday. In general:

$$TWA = \frac{C_aT_a+C_bT_b+\ldots+C_nT}{8}$$

where T_a = the time of the first exposure period during the shift
C_a = the concentration of contaminant in period *a*
T_b = another time period during the shift
C_b = the concentration during period *b*
T_n = the *n*th or final time period in the shift
C_n = the concentration during period *n*

This simply provides a summation throughout the workday of the product of the concentrations and the time periods for the concentrations encountered in each time interval and averaged over an 8-hour standard workday.

EVALUATION

Evaluation can be defined as the decision-making process resulting in an opinion on the degree of health hazard posed by chemical, physical, biological, or ergonomic stresses in industrial operations. The basic approach to controlling occupational disease consists of evaluating the potential hazard and controlling the specific hazard by suitable industrial hygiene techniques. (See Chapter 15, Evaluation, for more details.)

Evaluation involves judging the magnitude of the chemical, physical, biological, or ergonomic stresses. Determining whether a health hazard exists is based on a combination of observation, interviews, and measurement of the levels of energy or air contaminants arising from the work process as well as an evaluation of the effectiveness of control measures in the workplace. The industrial hygienist then compares environmental measurements with hygienic guides, TLVs, OSHA PELs, NIOSH RELs, or reports in the literature.

Evaluation, in the broad sense, also includes determining the levels of physical and chemical agents arising out of a process to study the related work procedures and to determine the effectiveness of a given piece of equipment used to control the hazards from that process.

Anticipating and recognizing industrial health hazards involve knowledge and understanding of the several types of workplace environmental stresses and the effects of these stresses on the health of the worker. Control involves the reduction of environmental stresses to values that the worker can tolerate without impairment of health or productivity. Measuring and quantitating environmental stress are the essential ingredients for modern industrial hygiene, and are instrumental in conserving the health and well-being of workers.

Basic Hazard-Recognition Procedures

There is a basic, systematic procedure for recognizing and evaluating environmental health hazards, which includes the following questions:

- ➢ What is produced?
- ➢ What raw material is used?
- ➢ What materials are added in the process?
- ➢ What equipment is involved?
- ➢ What is the cycle of operations?
- ➢ What operational procedures are used?
- ➢ Is there a written procedure for the safe handling and storage of materials?
- ➢ What about dust control, cleanup after spills, and waste disposal?
- ➢ Are the ventilating and exhaust systems adequate?
- ➢ Does the facility layout minimize exposure?
- ➢ Is the facility well-equipped with safety appliances such as showers, masks, respirators, and emergency eyewash fountains?
- ➢ Are safe operating procedures outlined and enforced?
- ➢ Is a complete hazard communication program that meets state or federal OSHA requirements in effect?

Understand the industrial process well enough to see where contaminants are released. For each process, perform the following:

- ➢ For each contaminant, find the OSHA PEL or other safe exposure guideline based on the toxicological effect of the material.
- ➢ Determine the actual level of exposure to harmful physical agents.
- ➢ Determine the number of employees exposed and length of exposure.
- ➢ Identify the chemicals and contaminants in the process.
- ➢ Determine the level of airborne contaminants using air-sampling techniques.
- ➢ Calculate the resulting daily average and peak exposures from the air-sampling results and employee exposure times.
- ➢ Compare the calculated exposures with OSHA standards, the TLV listing published by the ACGIH, the NIOSH RELs, the hygienic guides, or other toxicological recommendations.

All of the above are discussed in detail in the following chapters.

Information Required

Detailed information should be obtained regarding types of hazardous materials used in a facility, the type of job operation, how the workers are exposed, work patterns, levels of air contamination, duration of exposure, control measures used, and other pertinent information. The hazard potential of the material is determined not only by its inherent toxicity, but also by the conditions of use (who uses what, where, and how long?).

To recognize hazardous environmental factors or stresses, a health and safety professional must first know the raw materials used and the nature of the products and by-products manufactured. Consult MSDSs for the substances.

Any person responsible for maintaining a safe, healthful work environment should be thoroughly acquainted with the concen-

trations of harmful materials or energies that may be encountered in the industrial environment for which they are responsible.

If a facility is going to handle a hazardous material, the health and safety professional must consider all the unexpected events that can occur and determine what precautions are required in case of an accident to prevent or control atmospheric release of a toxic material.

After these considerations have been studied and proper countermeasures installed, operating and maintenance personnel must be taught the proper operation of the health and safety control measures. Only in this way can personnel be made aware of the possible hazards and the need for certain built-in safety features.

The operating and maintenance people should set up a routine procedure (at frequent, stated intervals) for testing the emergency industrial hygiene and safety provisions that are not used in normal, ordinary facility or process operations.

Degree of Hazard

The degree of hazard from exposure to harmful environmental factors or stresses depends on the following:

- ➢ Nature of the material or energy involved
- ➢ Intensity of the exposure
- ➢ Duration of the exposure

The key elements to be considered when evaluating a health hazard are how much of the material in contact with body cells is required to produce injury, the probability of the material being absorbed by the body to result in an injury, the rate at which the airborne contaminant is generated, the total time of contact, and the control measures in use.

Air Sampling

The importance of the sampling location, the proper time to sample, and the number of samples to be taken during the course of an investigation of the work environment cannot be overstressed.

Although this procedure might appear to be a routine, mechanical job, actually it is an art requiring detailed knowledge of the sampling equipment and its shortcomings. The person taking the sample(s) needs to know where and when to sample; and how to weigh the many factors that can influence the sample results, such as ambient temperature, season of the year, unusual problems in work operations, and interference from other contaminants. The sample must usually be taken in the breathing zone of an employee (see Figure 1–5).

The air volume sampled must be sufficient to permit a representative determination of the contaminant to properly compare the result with the TLV or PEL. The sampling period must usually be sufficient to give a direct measure of the average full-shift exposure of the employees concerned. The sample must be sealed and identified if it is to be shipped to a laboratory so that it is possible to identify positively the time and place of sampling and the individual who took the sample.

Figure 1–5. Portable pump with intake positioned to collect continuous samples from the breathing zone of an employee. (Courtesy MSA)

Area samples, taken by setting the sampling equipment in a fixed position in the work area, are useful as an index of general contamination. However, the actual exposure of the employee at the point of generation of the contaminant can be greater than is indicated by an area sample.

To meet the requirement of establishing the TWA concentrations, the sampling method and time periods should be chosen to average out fluctuations that commonly occur in a day's work. If there are wide fluctuations in concentration, the long-term samples should be supplemented by samples designed to catch the peaks separately.

If the exposure being measured is from a continuous operation, it is necessary to follow the particular operator through two cycles of operation, or through the full shift if operations follow a random pattern during the day. For operations of this sort, it is particularly important to find out what the workers do when the equipment is down for maintenance or process change. Such periods are often also periods of maximum exposure. (See Chapter 16, Air Sampling.)

As an example of the very small concentrations involved, the industrial hygienist commonly samples and measures substances in the air of the working environment in concentrations ranging from 1 to 100 ppm. Some idea of the magnitude of these concentrations can be appreciated when one realizes that 1 inch in 16 miles is 1 part per million; 1 cent in $10,000, 1 ounce of salt in 62,500 pounds of sugar, and

1 ounce of oil in 7,812.5 gallons of water all represent 1 part per million.

OCCUPATIONAL SKIN DISEASES

Some general observations on dermatitis are given in this chapter, but more detailed information is given in Chapter 3, The Skin and Occupational Dermatoses. Occupational dermatoses can be caused by organic substances, such as formaldehyde, solvents or inorganic materials, such as acids and alkalis, and chromium and nickel compounds. Skin irritants are usually either liquids or dusts.

Types

There are two general types of dermatitis: primary irritation and sensitization.

PRIMARY IRRITATION DERMATITIS

Nearly all people suffer primary irritation dermatitis from mechanical agents such as friction, from physical agents such as heat or cold, and from chemical agents such as acids, alkalis, irritant gases, and vapors. Brief contact with a high concentration of a primary irritant or prolonged exposure to a low concentration causes inflammation. Allergy is not a factor in these conditions.

SENSITIZATION DERMATITIS

This type results from an allergic reaction to a given substance. The sensitivity becomes established during the induction period, which may be a few days to a few months. After the sensitivity is established, exposure to even a small amount of the sensitizing material is likely to produce a severe reaction.

Some substances can produce both primary irritation dermatitis and sensitization dermatitis. Among them are organic solvents, chromic acid, and epoxy resin systems.

Causes

Occupational dermatitis can be caused by chemical, mechanical, physical, and biological agents and plant poisons.

Chemical agents are the predominant causes of dermatitis in manufacturing industries. Cutting oils and similar substances are significant because the oil dermatitis they cause is probably of greater interest to industrial concerns than is any other type of dermatitis.

Detergents and solvents remove the natural oils from the skin or react with the oils of the skin to increase susceptibility to reactions from chemicals that ordinarily do not affect the skin. Materials that remove the natural oils include alkalis, soap, and turpentine.

Dessicators, hygroscopic agents, and anhydrides take water out of the skin and generate heat. Examples are sulfur dioxide and trioxide, phosphorus pentoxide, strong acids such as sulfuric acid, and strong alkalis such as potash.

Protein precipitants tend to coagulate the outer layers of the skin. They include all the heavy metallic salts and those that form alkaline albuminates on combining with the skin, such as mercuric and ferric chloride. Alcohol, tannic acid, formaldehyde, picric acid, phenol, and intense ultraviolet rays are other examples of protein-precipitating agents.

Oxidizers unite with hydrogen and liberate nascent oxygen on the skin. Such materials include nitrates, chlorine, iodine, bromine, hypochlorites, ferric chloride, hydrogen peroxide, chromic acid, permanganates, and ozone.

Solvents extract essential skin constituents. Examples are ketones, aliphatic and aromatic hydrocarbons, halogenated hydrocarbons, ethers, esters, and certain nitro compounds.

Allergic or anaphylactic proteins stimulate the production of antibodies that cause skin reactions in sensitive people. The sources of these antigens are usually cereals, flour, and pollens, but can include feathers, scales, flesh, fur, and other emanations.

Mechanical causes of skin irritation include friction, pressure, and trauma, which may facilitate infection with either bacteria or fungi.

Physical agents leading to occupational dermatitis include heat, cold, sunlight, x rays, ionizing radiation, and electricity. The x rays and other ionizing radiation can cause dermatitis, severe burns, and even cancer. Prolonged exposure to sunlight produces skin changes and may cause skin cancer.

Biological agents causing dermatitis can be bacterial, fungal, or parasitic. Boils and folliculitis caused by staphylococci and streptococci, and general infection from occupational wounds, are probably the best known among the bacterial skin infections. These can be occupationally induced infections.

Fungi cause athlete's foot and other types of dermatitis among kitchen workers, bakers, and fruit handlers; fur, hide, and wool handlers or sorters; barbers; and horticulturists. Parasites cause grain itch and often occur among handlers of grains and straws, and particularly among farmers, laborers, miners, fruit handlers, and horticulturists.

Plant poisons causing dermatitis are produced by several hundred species of plants. The best known are poison ivy, poison oak, and poison sumac. Dermatitis from these three sources can result from bodily contact with any part of the plant, exposure of any part of the body to smoke from the burning plant, or contact with clothing or other objects previously exposed to the plant.

Physical Examinations

Preplacement examinations help identify those especially susceptible to skin irritations. The examining physician should be given detailed information on the type of work for which the applicant is being considered. If the work involves exposure to skin irritants, the physician should determine whether the prospective employee has deficiencies or characteristics likely to predispose him or her to dermatitis (see Chapter 25, The Occupational Medicine Physician, for more details).

Preventive Measures

Before new or different chemicals are introduced in an established process, possible dermatitis hazards should be carefully considered. Once these hazards are anticipated, suitable engineering controls should be devised and built into the processes to avoid them.

The type, number, and amounts of skin irritants used in various industrial processes affect the degree of control that can be readily obtained, but the primary objective in every case should be to eliminate skin contact as completely as possible. The preventive measures discussed in Chapter 18, Methods of Control, can be adapted to control industrial dermatitis.

CONTROL METHODS

With employment in the United States shifting from manufacturing to the service sector, many workplaces today present nontraditional occupational health hazards. Industrial hygienists need to possess the skills to implement control methodology in both industrial settings and in workplaces such as laboratories, offices, health care facilities, and environmental remediation projects. Hazards can change with time as well, so that hazard control systems require continual review and updating.

Control methods for health hazards in the work environment are divided into three basic categories:

1. Engineering controls that engineer out the hazard, either by initial design specifications or by applying methods of substitution, isolation, enclosure, or ventilation. In the hierarchy of control methods, the use of engineering controls should be considered first.
2. Administrative controls that reduce employee exposures by scheduling reduced work times in contaminant areas (or during cooler times of the day for heat stress exposure, for example). Also included here is employee training that includes hazard recognition and specific work practices that help reduce exposure. (This type of training is required by law for all employees exposed to hazardous materials in the course of their work.)
3. Personal protective equipment the employees wear to protect them from their environment. Personal protective equipment includes anything from gloves to full body suits with self-contained breathing apparatus, and can be used in conjunction with engineering and administrative controls.

Engineering controls should be used as the first line of defense against workplace hazards wherever feasible. Such built-in protection, inherent in the design of a process, is preferable to a method that depends on continual human implementation or intervention. The federal regulations, and their interpretation by the Occupational Safety and Health Review commission, mandate the use of engineering controls to the extent feasible; if they are not sufficient to achieve acceptable limits of exposure, the use of personal protective equipment and other corrective measures may be considered.

Engineering controls include ventilation to minimize dispersion of airborne contaminants, isolation of a hazardous operation or substance by means of barriers or enclosures, and substitution of a material, equipment, or process to provide hazard control. Although administrative control measures can limit the duration of individual exposures, they are not generally favored by employers because they are difficult to implement and maintain. For similar reasons, control of health hazards by using respirators and protective clothing is usually considered secondary to the use of engineering control methods. (See Chapter 18, Methods of Control.)

Engineering Controls

Substituting or replacing a toxic material with a harmless one is a very practical method of eliminating an industrial health hazard. In many cases, a solvent with a lower order of toxicity or flammability can be substituted for a more hazardous one. In a solvent substitution, it is always advisable to experiment on a small scale before making the new solvent part of the operation or process.

A change in process often offers an ideal chance to improve working conditions as well as quality and production. In some cases, a process can be modified to reduce the hazard. Brush painting or dipping instead of spray painting minimizes the concentration of airborne contaminants from toxic pigments. Structural bolts in place of riveting, steam-cleaning instead of vapor degreasing of parts, and airless spraying techniques and electrostatic devices to replace hand-spraying are examples of process change. In buying individual machines, the need for accessory ventilation, noise and vibration suppression, and heat control should be considered before the purchase.

Noisy operations can be isolated from the people nearby by a physical barrier (such as an acoustic box to contain noise from a whining blower or a rip saw). Isolation is particularly useful for limited operations requiring relatively few workers or where control by any other method is not feasible.

Enclosing the process or equipment is a desirable method of control because it can minimize escape of the contaminant into the workroom atmosphere. Examples of this type of control are glove box enclosures and abrasive shot blast machines for cleaning castings.

In the chemical industry, isolating hazardous processes in closed systems is a widespread practice. The use of a closed system is one reason why the manufacture of toxic substances can be less hazardous than their use.

Dust hazards often can be minimized or greatly reduced by spraying water at the source of dust dispersion. "Wetting down" is one of the simplest methods for dust control. However, its effectiveness depends on proper wetting of the dust and keeping it moist. To be effective, the addition of a wetting agent to the water and proper and timely disposal of the wetted dust before it dries out and is redispersed may be necessary.

Ventilation

The major use of exhaust ventilation for contaminant control is to prevent health hazards from airborne materials. OSHA has ventilation standards for abrasive blasting, grinding, polishing and buffing operations, spray finishing operations, and open-surface tanks. For more details, see Chapter 19, Local Exhaust Ventilation, and Chapter 20, Dilution Ventilation of Industrial Workplaces.

A local exhaust system traps and removes the air contaminant near the generating source, which usually makes this method much more effective than general ventilation. Therefore, local exhaust ventilation should be used when exposures to the contaminant cannot be controlled by substitution, changing the process, isolation, or enclosure. Even though a process has been isolated, it still may require a local exhaust system.

General or dilution ventilation—removing and adding air to dilute the concentration of a contaminant to below hazardous levels—uses natural or forced air movement through open doors, windows, roof ventilators, and chimneys. General exhaust fans can be mounted in roofs, walls, or windows (see Chapters 19 and 20 for more details).

Consideration must be given to providing replacement air, especially during winter. Dilution ventilation is feasible only if the quantity of air contaminant is not excessive, and is particularly effective if the contaminant is released at a substantial distance from the worker's breathing zone. General ventilation should not be used where there is a major, localized source of contamination (especially highly toxic dusts and fumes). A local exhaust system is more effective in such cases.

Air conditioning does not substitute for air cleaning. Air conditioning is mainly concerned with control of air temperature and humidity and can be accomplished by systems that accomplish little or no air cleaning. An air-conditioning system usually uses an air washer to accomplish temperature and humidity control, but these air washers are not designed as efficient air cleaners and should not be used as such. (See Chapter 21, General Ventilation of Nonindustrial Occupancies.)

Processes in which materials are crushed, ground, or transported are potential sources of dust dispersion, and should be controlled either by wet methods or enclosed and ventilated by local exhaust ventilation. Points where conveyors are loaded or discharged, transfer points along the conveying system, and heads or boots of elevators should be enclosed as well as ventilated. (For more details, see Chapter 19, Local Exhaust Ventilation.)

Personal Protective Equipment

When it is not feasible to render the working environment completely safe, it may be necessary to protect the worker from that environment by using personal protective equipment. This is considered a secondary control method to engineering and administrative controls and should be used as a last resort.

Where it is not possible to enclose or isolate the process or equipment, ventilation or other control measures should be provided. Where there are short exposures to hazardous concentrations of contaminants and where unavoidable spills may occur, personal protective equipment must be provided and used.

Personal protective devices have one serious drawback: They do nothing to reduce or eliminate the hazard. They interpose a barrier between worker and hazard; if the barrier fails, immediate exposure is the result. The supervisor must be constantly alert to make sure that required protective equipment is worn by workers who need supplementary protection, as may be required by OSHA standards. (See Chapter 22, Respiratory Protection.)

Administrative Controls

When exposure cannot be reduced to permissible levels through engineering controls, as in the case of air contaminants or noise, an effort should be made to limit the employee's exposure through administrative controls.

Examples of some administrative controls are as follows:

- Arranging work schedules and the related duration of exposures so that employees are minimally exposed to health hazards
- Transferring employees who have reached their upper permissible limits of exposure to an environment where no further additional exposure will be experienced

Where exposure levels exceed the PEL for one worker in one day, the job can be assigned to two, three, or as many workers as needed to keep each one's duration of exposure within the PEL. In the case of noise, other possibilities may involve intermittent use of noisy equipment.

Administrative controls must be designed only by knowledgeable health and safety professionals, and used cautiously and judiciously. They are not as satisfactory as engineering controls and have been criticized by some as a means of spreading exposures instead of reducing or eliminating the exposure.

Good housekeeping plays a key role in occupational health protection. Basically, it is a key tool for preventing dispersion of dangerous contaminants and for maintaining safe and healthful working conditions. Immediate cleanup of any spills or toxic material, by workers wearing proper protective equipment, is a very important control measure. Good housekeeping is also essential where solvents are stored, handled, and used. Leaking containers or spigots should be fixed immediately, and spills cleaned promptly. All solvent-soaked rags or absorbents should be placed in airtight metal receptacles and removed daily.

It is impossible to have an effective occupational health program without good maintenance and housekeeping. Workers should be informed about the need for these controls. Proper training and education are vital elements for successful implementation of any control effort, and are required by law as part of a complete federal or state OSHA hazard communication program. (See Chapter 18, Methods of Control.)

SOURCES OF HELP

Specialized help is available from a number of sources. Every supplier of products or services is likely to have competent professional staff who can provide technical assistance or guidance. Many insurance companies that carry workers' compensation insurance provide industrial hygiene consultation services, just as they provide periodic safety inspections.

Professional consultants and privately owned laboratories are available on a fee basis for concentrated studies of a specific problem or for a facilitywide or companywide survey, which can be undertaken to identify and catalog individual environmental exposures. Lists of certified analytical laboratories and industrial hygiene consultants are available from the AIHA.

Many states have excellent industrial hygiene departments that can provide consultation on a specific problem. Appendix A, Additional Resources, contains names and addresses of state and national health and hygiene agencies. NIOSH has a Technical Information Center that can provide information on specific problems. Scientific and technical societies that can help with problems are listed in Appendix A. Some provide consultation services to nonmembers; they all have much accessible technical information. A list of organizations concerned with industrial hygiene is included in Appendix A.

SUMMARY

No matter what health hazards are encountered, the approach of the industrial hygienist is essentially the same. Using methods relevant to the problem, he or she secures qualitative and quantitative estimates of the extent of hazard. These data are then compared with the recommended exposure guidelines. If a situation hazardous to life or health is shown, recommendations for correction are made. The industrial hygienist's recommendations place particular emphasis on effectiveness of control, cost, and ease of maintenance of the control measures.

Anticipation, recognition, evaluation, and control are the fundamental concepts of providing all workers with a healthy working environment.

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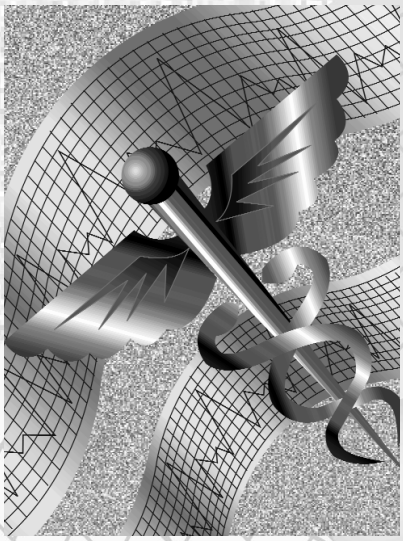

Anatomy, Physiology, and Pathology

Part II

Chapter 2

The Lungs

by George S. Benjamin, MD, FACS
revised by John Balmes, MD

The material in this chapter on human respiration is intended primarily for engineers and health and safety professionals who must evaluate and control industrial health hazards.

Establishing an effective industrial hygiene program calls for an understanding of the anatomy and physiology of the human respiratory system. The respiratory system is a quick and direct avenue of entry for toxic materials into the body because of its intimate association with the circulatory system and the constant need to oxygenate human tissue cells. Anything affecting the respiratory system, whether it is insufficient oxygen or contaminated air, can affect the entire human organism.

Humans can survive for weeks without food and for days without water, but for only a few minutes without air. Air must reach the lungs almost constantly so oxygen can be extracted and distributed via the blood to every body cell. The life-giving component of air is oxygen, which constitutes a little less than one-fifth of its volume.

All living cells of the body are engaged in a series of chemical processes. The total of these processes is metabolism. In the course of the body's metabolism, each cell consumes oxygen and produces carbon dioxide as a waste substance.

Each living cell in the body requires a constant supply of oxygen. Some cells, however, are more vulnerable than others; cells in the brain and heart may die after 4–6 minutes without oxygen. These cells can never be replaced, and permanent changes result from such damage. Other cells in the body are not so critically dependent on an oxygen supply because they are replaceable.

Thus, the respiratory system by which oxygen is delivered to the body and carbon dioxide removed is a very important part of the body. The respiratory system consists of all the organs of the body that contribute to normal respiration or breathing. Strictly speaking, it includes the nose, mouth, upper throat, larynx, trachea, and bronchi, which are all air passages or airways. It includes the lungs, where oxygen is passed into the blood and carbon dioxide is

given off. Finally, it includes the diaphragm and the muscles of the chest, which permit normal respiratory movements (Figure 2–1).

ANATOMY

The human respiratory system includes the nose, the pharynx, the larynx, the trachea, the bronchi, and the lungs. Each is discussed in the following sections.

Nose

The nose consists of an external and an internal portion. The external portion of the nose protrudes from the face and is highly variable in shape. The upper part of this triangular structure is held in a fixed position by the supporting nasal bones that form the bridge of the nose. The lower portion is movable because of its pliable framework of fibrous tissue, cartilage, and skin.

The internal portion of the nose lies within the skull between the base of the cranium and the roof of the mouth, and is in front of the nasopharynx (the upper extension of the throat). The skull bones that enter into the formation of the nose include the frontal, the sphenoid, the ethmoid, the nasal, the maxillary, the lacrimal, the vomer, and the palatine and inferior conchae.

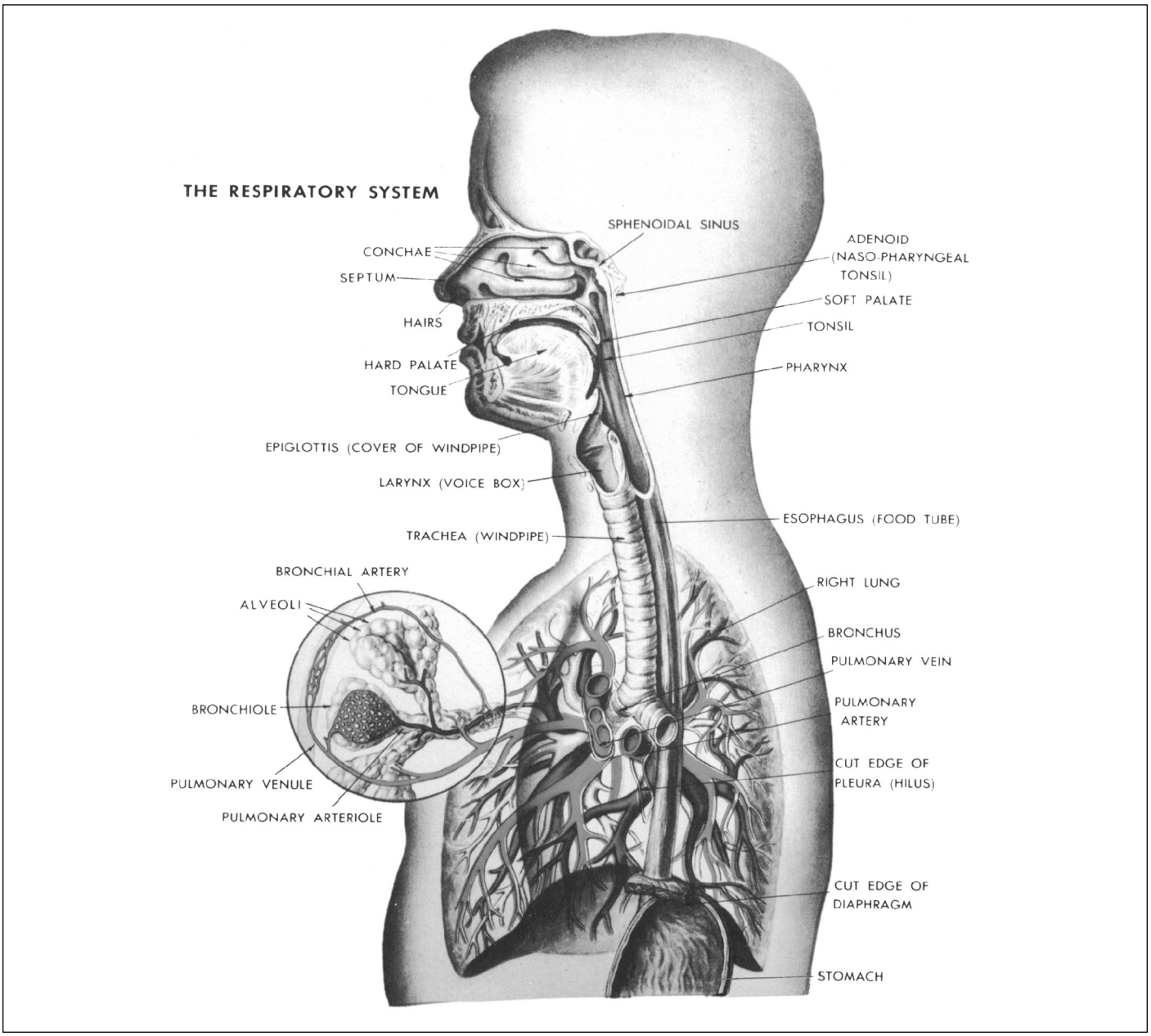

Figure 2–1. Schematic drawing of the respiratory system. (Reprinted with permission from *The Wonderful Human Machine.* Chicago: American Medical Association, 1971.)

The nasal septum is a narrow partition that divides the nose into right and left nasal cavities. In some people the nasal septum is markedly deflected to one side, causing the affected nasal cavity to be almost completely obstructed; this condition is called a deviated nasal septum.

The nasal cavities are open to the outside through the anterior nares (or nostrils); toward the rear, they open into the nasopharynx by means of the posterior nares, or conchae. The vestibule of each cavity is the dilated portion just inside the nostril. Toward the front, the vestibule is lined with skin and presents a ring of coarse hairs that serve to trap dust particles. Toward the rear, the lining of the vestibule changes from skin to a highly vascular ciliated mucous membrane, called the nasal mucosa, which lines the rest of the nasal cavity.

Extending into the nasal cavity from the base of the skull are large nerve filaments, which are part of the sense organ for smell. From these filaments, information on odors is relayed to the olfactory nerve, which goes to the brain.

TURBINATES

Near the middle of the nasal cavity and on both sides of the septum are a series of scroll-like bones called the conchae, or turbinates. The purpose of the turbinates is to increase the amount of tissue surface within the nose so that incoming air has a greater opportunity to be conditioned before it continues to the lungs.

Respiration begins with the nose, which is specially designed for the purpose, although there are times when you breathe through the mouth as well. When you perform any vigorous activity and begin to puff and pant, you are breathing rapidly through the mouth to provide the blood with the extra oxygen needed.

However, the mouth is not designed for breathing. You may have noticed this on cold days when you make a deliberate effort to keep your mouth tightly closed, because if you take air in through the mouth you can feel its coldness. Cold air passing through the mouth has no chance to become properly warmed. But cold as the air may be, you can breathe comfortably through the nose.

Air enters through the nares or nostrils, passes through a web of nasal hairs, and flows posteriorly toward the nasopharynx. The air is warmed and moistened in its passage and partially depleted of particles. Some particles are removed by impaction on the nasal hairs and at bends in the air path, and others by sedimentation.

In mouth breathing, some particles are deposited, primarily by impaction, in the oral cavity and at the back of the throat. These particles are rapidly passed to the esophagus (food tube) by swallowing.

MUCUS

The surfaces of the turbinates, like the rest of the interior walls of the nose, are covered with mucous membranes. These membranes secrete a fluid called mucus. The film of mucus is produced continuously and drains slowly into the throat. The mucus gives up heat and moisture to incoming air and serves as a trap for bacteria and dust in the air. It also helps dilute any irritating substances in the air.

The common cold involves an inflammation of the mucous membrane of the nose. It is characterized by an acute congestion of the mucous membrane and increased secretion of mucus. It is difficult to breathe through the nose because of the swelling of the mucous membrane and the accumulated secretions clogging the air passageway.

In cold weather, the membranes can increase the flow of mucus. If the atmosphere is unusually dry, as in an improperly heated building, the mucus may lose its moisture too rapidly and the membrane may become dry and irritated.

CILIA

In addition to the mucus, the membrane is coated with cilia, or hairlike filaments, that move in coordinated waves to propel mucus and trapped particles toward the nostrils. The millions of cilia lining the nasal cavity help the mucus clean the incoming air. When you breathe through the mouth, the protective benefits of the cilia and mucus are lost.

In summary, the nose serves not only as a passageway for air going to and from the lungs but also as an air conditioner and as the sense organ for smell. The importance of breathing through the nose is obvious as it moistens, filters, and warms or cools the air that is on its way to the lungs (Figure 2–2).

Throat

From the nasal cavity, air moves into the pharynx, or throat. Seven tubes enter the pharynx: the two from the nasal cavity, the eustachian tubes (which lead to the ears), the mouth cavity, the opening of the esophagus, and the opening of the trachea (windpipe).

PHARYNX

The pharynx, or throat, is a tubular passageway attached to the base of the skull and extending downward behind the nasal cavity, the mouth, and the larynx to continue as the esophagus. Its walls are composed of skeletal muscle and the lining consists of mucous membrane. The nasal passage joins the esophagus just behind the mouth. The union of the two passageways at this point makes it possible to breathe with reasonable comfort through the mouth when the nasal passages are blocked because of a cold or allergy.

NASOPHARYNX

The nasopharynx is the superior portion of the pharyngeal cavity; it lies behind the nasal cavities and above the level of the soft palate. This portion of the upper respiratory tract serves as a major defense against infectious organisms. Its ciliated mucosal lining is continuous with that of the nasal cavities. Immediately beneath the mucosa are collections of lymphoid tissue, the adenoids. The adenoids and tonsils, lower down in the throat, are part of the immune system and serve as a first defense against infectious organisms.

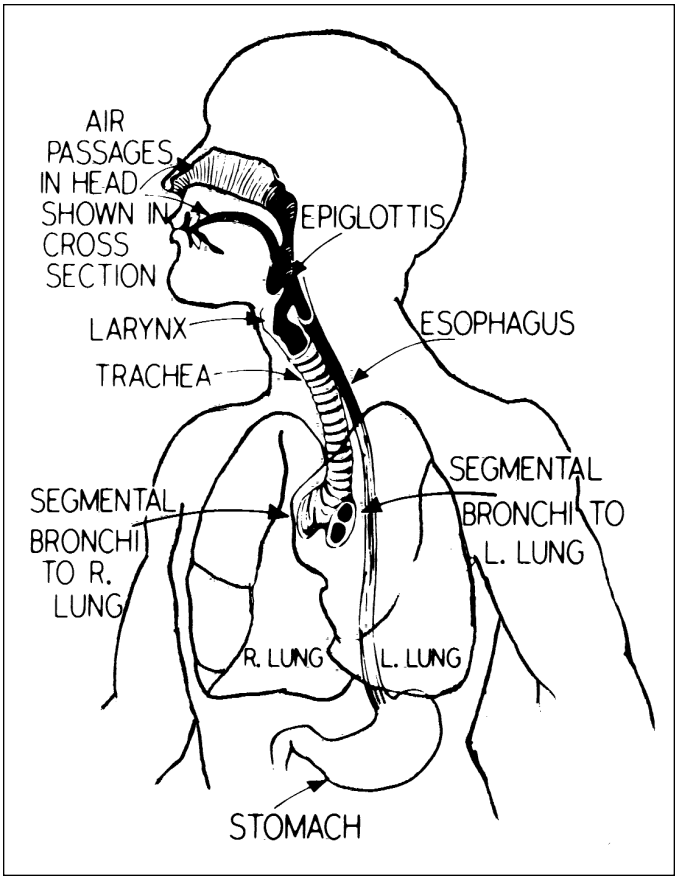

Figure 2–2. Parts of the human respiratory system. Air enters through the mouth and nose, passes down the trachea and into the lungs. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 1. Chicago, IL, American Academy of Orthopaedic Surgeons, 1971.)

ESOPHAGUS AND TRACHEA

At the bottom of the throat are two passageways: the esophagus behind and the trachea in front. Food and liquids entering the pharynx pass into the esophagus, which carries them to the stomach. Air and other gases enter the trachea to go to the lungs.

EPIGLOTTIS

Guarding the opening of the trachea is a thin, leaf-shaped structure called the epiglottis (Figure 2–3). This structure helps food glide from the mouth to the esophagus.

Everyone is aware that swallowing food and breathing cannot take place at the same time without danger of choking. But nature has devised a way for food and air to use the same general opening, the pharynx, with only an occasional mix-up.

The incoming air travels through the nasal cavity and through the larynx by crossing over the path used by food on its way to the stomach. Similarly, food crosses over the route of air. When food is swallowed, the larynx rises against the base of the tongue to help seal the opening.

If food accidentally starts down the wrong way, into the lungs rather than the stomach, there are explosive protests from the lungs. Any contact of a sizable liquid or solid particle with the trachea sets off a cough, an explosive expulsion of air that blows it out again. A cough can be a very powerful force. A slight breathing in, closing of the glottis, buildup of pressure, and a sudden release of the trapped air are involved. Also, stimulation of the larynx can cause spasm of the vocal cords, with total obstruction of breathing.

Normally, swallowing blocks off the glottis, halts breathing briefly, and ensures correct division of air and food. However, an unconscious person may lack this automatic response, and if a drink is given, it may proceed straight into the lungs.

The diaphragm is sometimes subject to periodic spasms of contraction that enlarge the lung cavities and lead to a quick inrush of air. The vocal cords come together to stop the flow, and the air, so suddenly set into motion and so suddenly stopped, makes the sharp noise called the hiccup. Hiccups may be due to indigestion, overloaded stomach, irritation under the surface of the diaphragm, too much alcohol, or many other possible causes, including heart attacks.

Larynx

The larynx, or voice box, serves as a passageway for air between the pharynx and the trachea. It lies in the midline of the neck, below the hyoid bone and in front of the laryngopharynx. The unique structure of the larynx enables it to function somewhat like a valve on guard duty at the entrance to the windpipe, controlling air flow and preventing anything but air from entering the lower air passages. Exhalation of air through the larynx is controlled by voluntary muscles; thus, the larynx is the organ of voice.

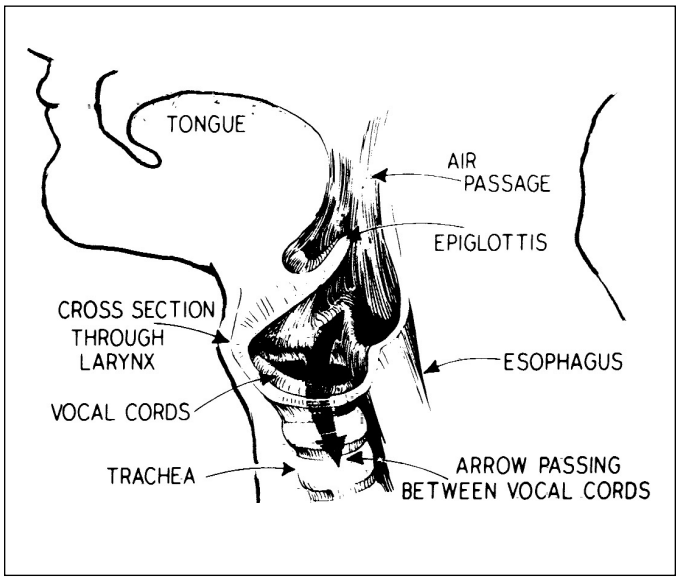

Figure 2–3. The anatomy of the neck: the epiglottis, larynx, vocal cords, trachea, and esophagus. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 1. Chicago, IL, American Academy of Orthopaedic Surgeons, 1971.)

The larynx is a triangular box composed of nine cartilages joined together by ligaments and controlled by skeletal muscles. The larynx is lined with ciliated mucous membrane (except the vocal folds), and the cilia move particles upward to the pharynx.

VOCAL CORDS

The larynx is at the top of the windpipe, or trachea, which takes air to the lungs. Although incoming air passes through the boxlike larynx, it is actually air expelled from the lungs that makes voice sounds. In the front of the larynx, two folds of membranes, the vocal cords, are attached and held by tiny cartilages. Muscles attached to the cartilages move the vocal cords, which are made to vibrate by air exhaled from the lungs.

During ordinary breathing, the vocal cords are held toward the walls of the larynx so that air can pass without being obstructed. During speech, the vocal cords swing over the center of the tube and muscles contract to tense the vocal cords.

SPEECH

Sounds are created as air is forced past the vocal cords, making them vibrate. These vibrations make the sound. You can feel these vibrations by placing your fingers lightly on your larynx (Adam's apple) while speaking.

The vibrations are carried through the air upward into the pharynx, mouth, nasal cavities, and sinuses, which act as resonating chambers. The greater the force and amount of air from the lungs, the louder the voice. Pitch differences result from variations in the tension of the cords. The larger the larynx and the longer the cords, the deeper the voice. The average man's vocal cords are about 0.75 in. (1.9 cm) long. Shorter vocal cords give women higher-pitched voices. Words and other understandable sounds are formed by the tongue and muscles of the mouth.

Infections of the throat and nasal passages alter the shape of the resonating chambers and change the voice, roughening it so that it sounds hoarse. When the membranes of the larynx themselves are affected (laryngitis), speech may be reduced to a whisper. In whispering, the vocal cords are not involved; sound is produced by tissue folds, sometimes called false vocal cords, that lie just above the vocal cords themselves.

Trachea

The trachea or windpipe is a tube about 4.5 in. (11.5 cm) long and 1 in. (2.5 cm) in diameter, extending from the bottom of the larynx through the neck and into the chest cavity. At its lower end it divides into two tubes, the right and left bronchi. The esophagus, which carries food to the stomach, is immediately behind the trachea.

Rings of cartilage hold the trachea and bronchi open. If the head is tilted back, the tube can be felt as the fingers run down the front of the neck. The ridges produced by the alternation of cartilage and fibrous tissue are also felt, giving the tube a feeling of roughness.

The windpipe wall is lined with mucous membrane and with many hairlike cilia fanning upward toward the throat, moving dust particles that have been caught in the sticky membrane away from the lungs.

The path of the esophagus, which carries food to the stomach, runs immediately behind the trachea. At the point behind the middle of the breastbone, where the aorta arches away from the heart, the trachea divides into two branches: the right and the left bronchi.

Respiratory infections such as colds and sore throats may sometimes extend down into the trachea; they are then called tracheitis. Inflammation of the walls of these passages causes harsh breathing and deep cough.

Bronchi

The trachea divides into the right and left main stem bronchi under the sternum (breastbone), approximately where the second and third ribs connect to the sternum. Each bronchus enters the lung of its own side through the hilus (an opening through which vessels or nerves enter or leave an organ).

The right main stem bronchus is wider and shorter than the left. Its direction is almost identical to that of the trachea. That is why most aspirated material enters the right lung.

Each bronchus leads to a separate lung, and in doing so divides and subdivides into increasingly smaller, finer, and more numerous tubes, something like the branches of a tree; the whole structure is sometimes called the bronchial tree. In the larger branches there also is stiffening by rings of cartilage, but as the branches get smaller the cartilage diminishes to small plates and finally disappears.

The smaller branches of the bronchial tree, bronchioles, are another possible source of discomfort. The fine subdivisions of the air passages are lined by circular muscles, which through contraction or relaxation can alter the diameter, thus helping to control the flow of air through the lungs. Sometimes, as a result of infection or an allergic reaction to some foreign substance, there is a spasmodic contraction of the small muscles and a swelling of the mucous membrane of the bronchioles. The air passages narrow and airflow is reduced.

Lungs

There are two lungs, one on each side of the thoracic cage (Figure 2–4). The lungs are suspended within the thoracic cage by the trachea, by the arteries and veins running to and from the heart, and by pulmonary ligaments.

The lungs extend from the collarbone to the diaphragm, one on the right side of the body and one on the left. Taken together, they fill almost all of the thoracic cavity. The two lungs are not quite mirror images of each other. The right lung, slightly the larger of the two, is partially divided into three lobes; the left lung is divided into only two.

The mediastinum is the compartment between the left and right lung. It contains the heart, great vessels (aorta, vena cava, pulmonary veins, and arteries), nerves, trachea, main stem bronchi, and esophagus.

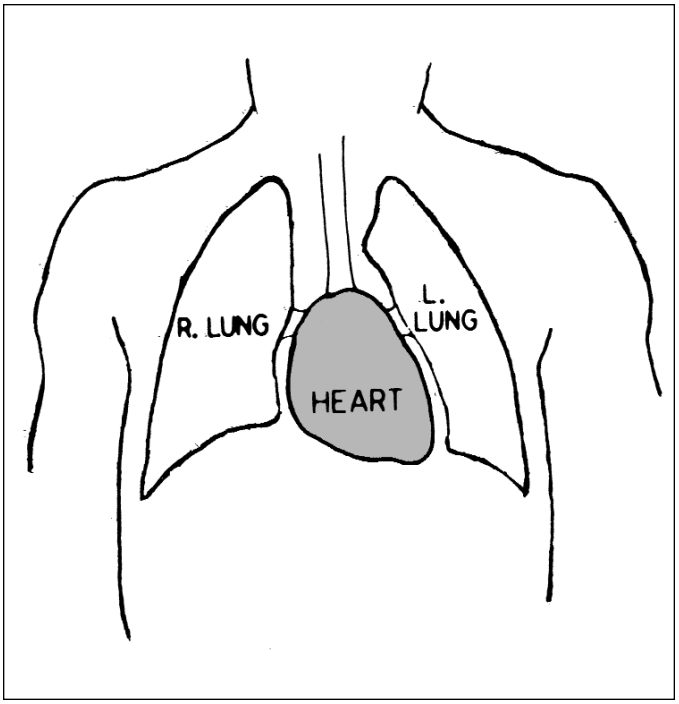

Figure 2–4. The relative size and spatial relationship of the human heart and lungs. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 1. Chicago, IL, American Academy of Orthopaedic Surgeons, 1971.)

PLEURA

The lungs are covered by a double membrane. One, the pleural membrane, lies over the lungs; the other lines the chest cavity (Figure 2–5). They are separated by a thin layer of fluid that, during breathing, prevents the two membranes from rubbing against each other. Inflammation of the pleura can cause roughness and irritation, the condition called pleurisy.

The potential intrapleural space (between the two pleural layers) has a negative atmospheric pressure during inspiration (breathing in). An introduction of air between the pleural layers (pneumothorax) would decrease or disrupt this negative pressure and the lung would partially or totally collapse.

The tendency to collapse is counteracted by a pull in the opposite direction. The lung surface is held tenaciously to the chest wall not by physical bonds, but by the negative pressure of the intrapleural space. Normally, this negative pressure acts somewhat like a suction cup to pull the lung against the chest wall and keep it expanded.

ALVEOLI

Within a lung, the bronchi divide and subdivide, becoming smaller and smaller, until the branches reach a very fine size and are called bronchioles. *Acini* or terminal lung units are supplied by a terminal bronchiole from which multiple respiratory bronchioles branch off. The respiratory bronchioles lead into several ducts; each duct ends in a cluster of air sacs, which resemble a tiny bunch of grapes called alveoli (Figure 2–6).

The walls of the alveoli are two cells thick and oxygen can pass freely across those thin membranes. It can pass freely in both directions, of course, but the blood coming to the lungs has a lower partial pressure of oxygen than inspired air, so the net exchange is from the lungs to the bloodstream.

The human respiratory tract branches successively from the trachea to 25–100 million branches. These branches terminate in some 300 million air sacs, or alveoli. The cross section of the trachea is about 0.31 sq in. (2 cm^2) and the combined cross sections of the alveolar ducts, which handle about the same quantity of air, are about 8 ft^2 (8,000 cm^2).

The respiratory surface in the lungs ranges from about 300 ft^2 (28 m^2) at rest to about 1,000 ft^2 (93 m^2) at deepest inspiration. The membrane separating the alveolar air space from circulating blood may be only one or two cells thick. In the course of an eight-hour day of moderate work, a human breathes about 300 ft^3 (8.5 m^3) of air. Contrast the forced ventilation exposure of the large delicate lung surface with the

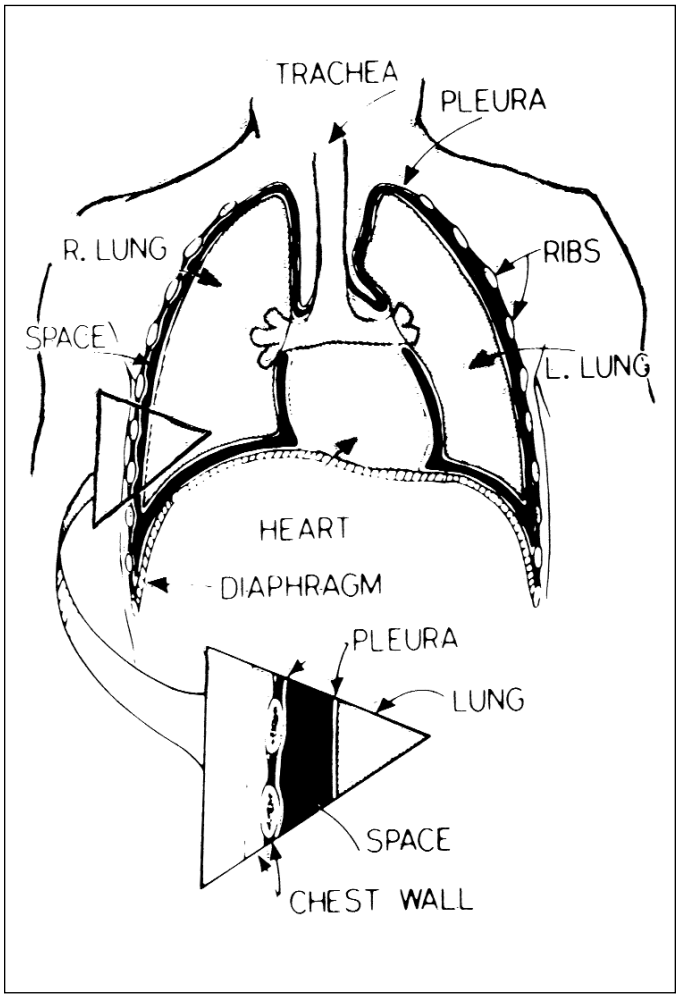

Figure 2–5. The lungs, pleura, and pleural space. Inset shows the chest wall relationships. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 1, Chicago, IL, American Academy of Orthopaedic Surgeons, 1971.)

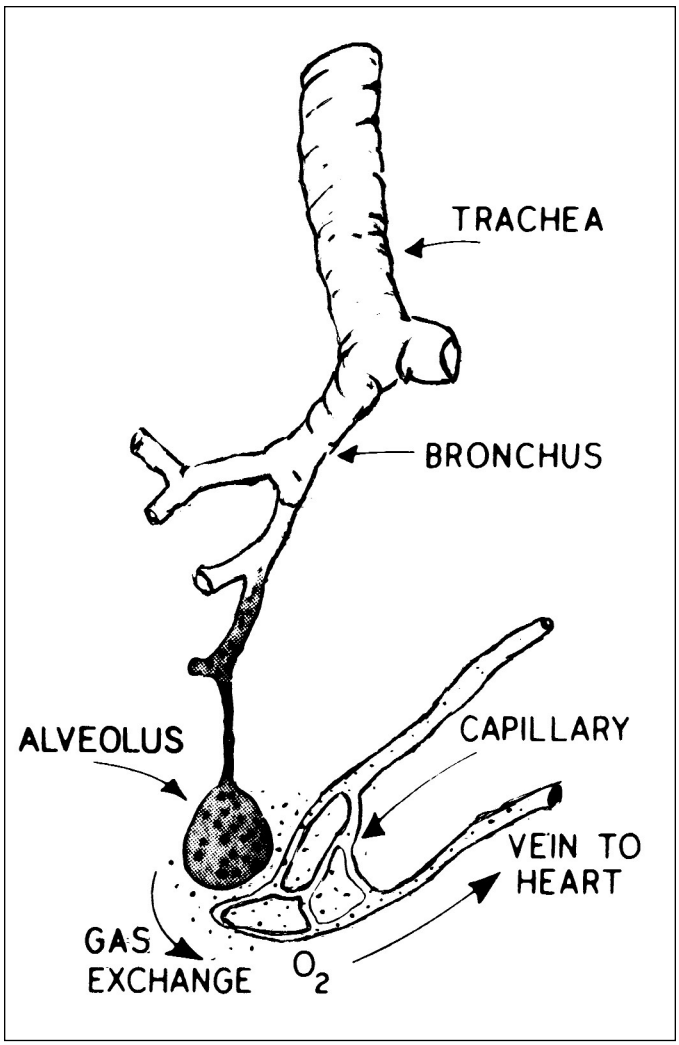

Figure 2–6. The branching characteristic of the trachea into smaller airways ending in an alveolus is shown. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 1, Chicago, IL, American Academy of Orthopaedic Surgeons, 1971.)

ambient air exposure of the skin, which has some 20 ft^2 (1.9 m^2) of surface and a thickness measured in millimeters. It is evident that the lungs represent by far the most extensive and intimate contact of the body with the ambient atmosphere.

The respiratory tract, with its successive branches and tortuous passageways, is a highly efficient dust collector. Essentially all particles entering the respiratory system larger than 4 or 5 micrometers (μm) are deposited in it. About half of those of 1-μm size appear to be deposited and the other half exhaled. The sites of deposition in the system are different for various sizes. Discussion of dust deposition in the respiratory system is simplified by the concept of equivalent size of particles. The equivalent size of a particle is the diameter of a unit density sphere, which has the same terminal settling velocity in still air as does the particle.

Particles greater than 2.5 or 3 μm equivalent size are deposited, for the most part, in the upper respiratory system—that is, the nasal cavity, the trachea, the bronchial tubes, and other air passages—whereas particles 2 μm in equivalent size are deposited about equally in the upper respiratory system and in the alveolar or pulmonary air spaces. Particles about 1 μm in equivalent size are deposited more efficiently in the alveolar spaces than elsewhere; essentially none are collected in the upper respiratory system. For more details, see Chapter 8, Particulates.

RESPIRATION

The process through which the body combines oxygen with food substances, and thus produces energy, is called metabolism (Figure 2–7). The term *respiration* refers to the tissue enzyme oxidation processes that use oxygen and produce carbon dioxide. More generally, this term designates the phases of oxygen supply and carbon dioxide removal. The following are the general subdivisions of the overall process:

- ➢ Breathing—movement of chest/lung complex to ventilate the alveoli
- ➢ External respiration—exchange of gas (oxygen and carbon dioxide) between lung (alveolar) air and blood
- ➢ Internal respiration—exchange of gas between tissue blood and the tissue cells
- ➢ Intracellular respiration—ultimate utilization of oxygen by the cells with the coincident release of carbon dioxide.

To a biochemist, *respiration* refers to the enzymatic processes in the tissues that use oxygen and produce carbon dioxide. The blood contains a chemical that is part protein and part iron pigment, called hemoglobin. The hemoglobin binds oxygen when the blood flows through regions where oxygen is plentiful—as in the alveoli—and releases it to tissues that are consuming oxygen. Similarly, the carbon dioxide produced when the body cells burn fuel is dissolved in the bloodstream as it flows through tissues where carbon dioxide is plentiful, and is released in the lungs, where carbon dioxide is comparatively scarce.

Carbon dioxide is always present in the atmosphere, but the proportion of carbon dioxide in air exhaled from the lungs is 100 times greater. The proportion of water vapor in air exhaled from the lungs is about 10 times greater than that of the normal atmosphere. Everyone has no doubt noticed the moisture that accumulates on a glass window when the nose and mouth are close to it. Breath appears as a white cloud on cold days because the low temperature of the air causes the exhaled water vapor to condense.

Gas Exchange

Gases diffuse rapidly from areas of higher to lower concentrations. The concentration of oxygen is higher in alveolar air than it is in the blood coming to the lungs from the right ventricle. Therefore, oxygen diffuses into the blood from the alveolar air. On the other hand, the concentration of oxygen is low in the cells of the body tissues and in tissue fluid; therefore, oxygen diffuses from the blood in the capillaries into the tissue fluid and into cells.

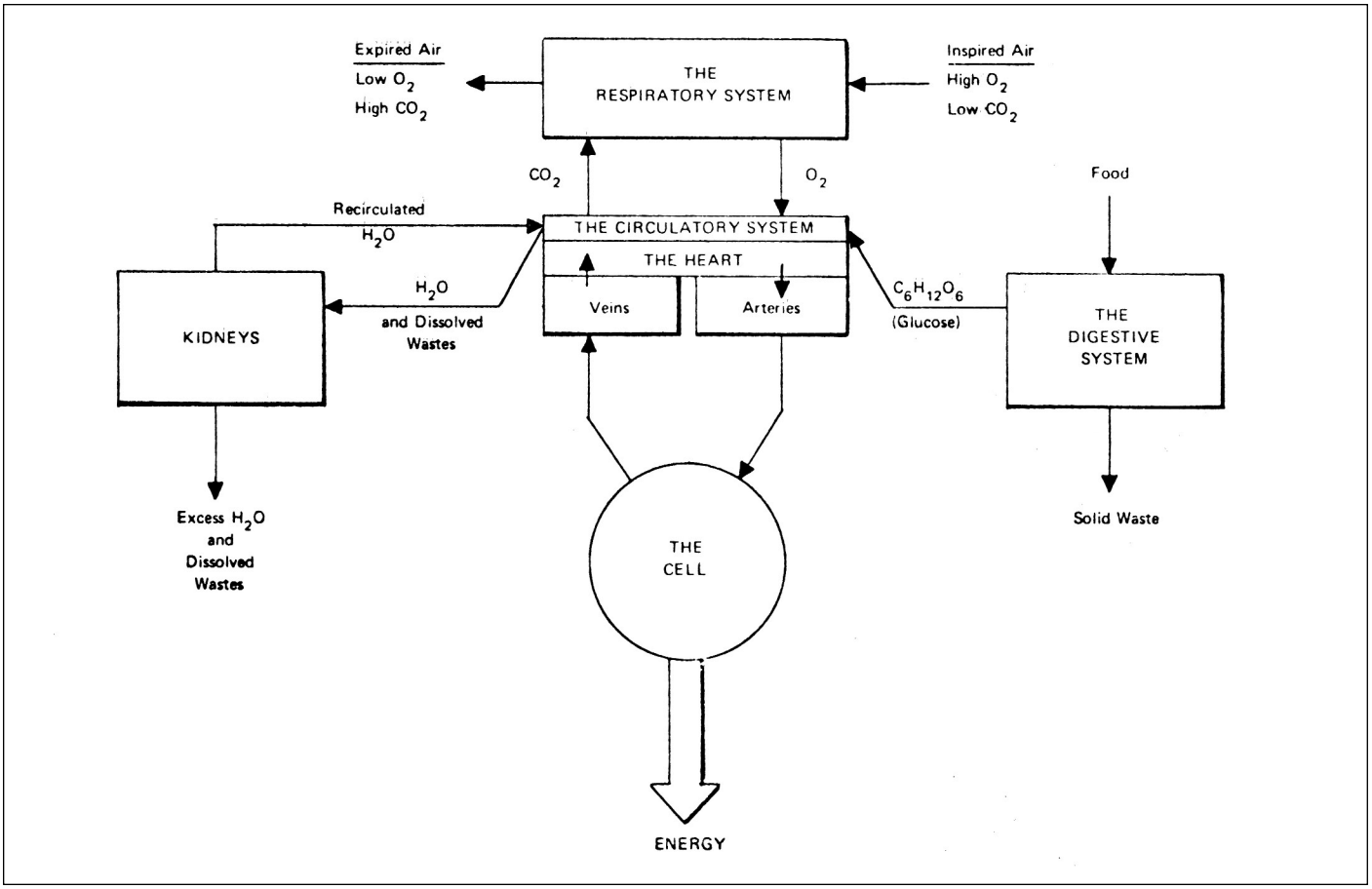

Figure 2–7. The conversion of food into energy (the metabolic process) is illustrated. (Reprinted from *A Guide to Industrial Respiratory Protection,* NIOSH Publication No. 76–189, 1976.)

EQUALIZING PRESSURES

If there is a pressure difference across a permeable membrane such as that separating the alveoli from the pulmonary capillaries, gas molecules pass from the high- to low-pressure region until the pressures are equalized (Figure 2–8).

The concentration of carbon dioxide in tissue cells and tissue fluid is higher than in the blood in capillaries. Therefore, carbon dioxide diffuses from tissue cells and tissue fluid into the blood. The concentration of carbon dioxide is higher in blood coming to the lungs from the right ventricle than it is in alveolar air; therefore, it diffuses from blood in pulmonary capillaries into the alveolar air.

On entering the bloodstream, both oxygen and carbon dioxide immediately go into simple physical solution in the plasma. However, because the plasma can hold only a small amount of gas in solution, most of the oxygen and carbon dioxide quickly enter into chemical combinations with other blood constituents.

OXYGEN TENSION

Only a small amount of oxygen is carried in solution in the plasma. However, it is this oxygen that exerts tension or pressure and is available for immediate diffusion when blood reaches the systemic capillaries (Figure 2–9). The remaining oxygen in the blood is combined with hemoglobin in the red blood cells to form oxyhemoglobin (HbO_2). This oxygen is given up readily by hemoglobin whenever the oxygen tension of plasma decreases, so that as oxygen diffuses from plasma in tissue capillaries it is replenished by more from oxyhemoglobin. Hemoglobin that has given up its load of oxygen is called *reduced* hemoglobin (Hb) (Figure 2–10). See Chapter 6, Industrial Toxicology, for more details.

In most people during routine activities, the depth and rate of breathing movements are regulated for the maintenance of carbon dioxide in the arterial blood. Low oxygen tension can stimulate breathing, but only when the oxygen content of the inspired gases is reduced to nearly half that in air at sea level. Oxygen partial pressure, except in some unusual circumstances, is usually high enough that breathing is regulated by the body requirements for carbon dioxide.

The oxygen content of lung air is determined by the oxygen content of the inspired gases, the flushing of the lungs required for carbon dioxide regulation, and the rate of oxygen uptake by the blood as it passes through the lungs.

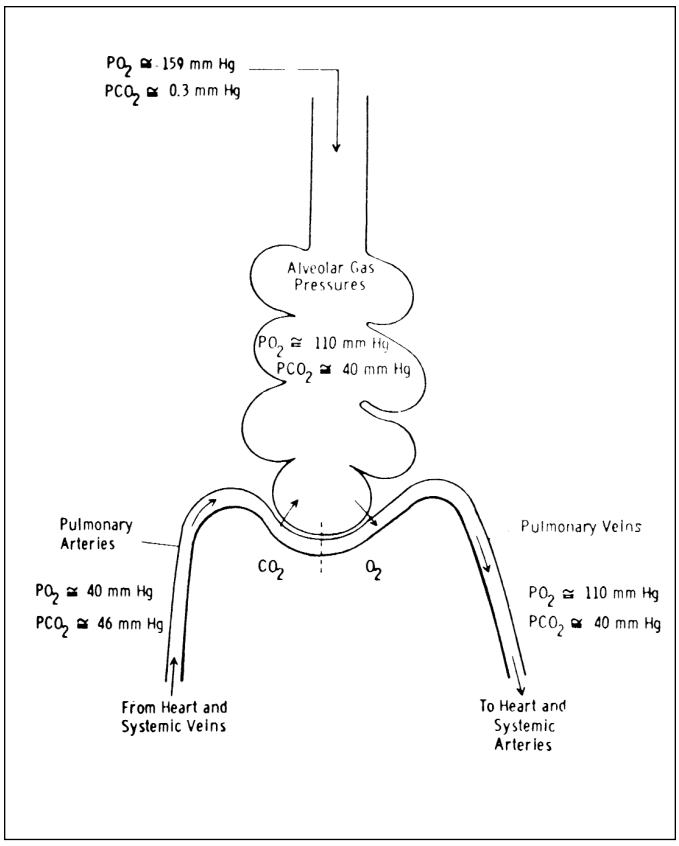

Figure 2–8. Partial pressures of various gases involved in the gas exchange in the lungs are shown. (Reprinted from *A Guide to Industrial Respiratory Protection,* NIOSH Publication No. 76–189, 1976.)

Mechanics of Breathing

Breathing is the act of taking fresh air into and expelling stale air from the lungs. Breathing is accomplished by changes in the size of the chest cavity. Twelve pairs of ribs surround and guard the lungs. The ribs are joined to the spine at the back and curve around the chest to form a cage. In front, the top seven pairs are connected to the sternum (breastbone). The next three pairs are connected to the rib above. The last two pairs, unconnected in front, are called floating ribs. The entire cage is flexible and can be expanded readily by special muscles. The rib cage forms the wall of the chest; the dome-shaped diaphragm forms the floor of the chest cavity. The diaphragm is attached to the breastbone in front, the spinal column in back, and the lower ribs on the sides.

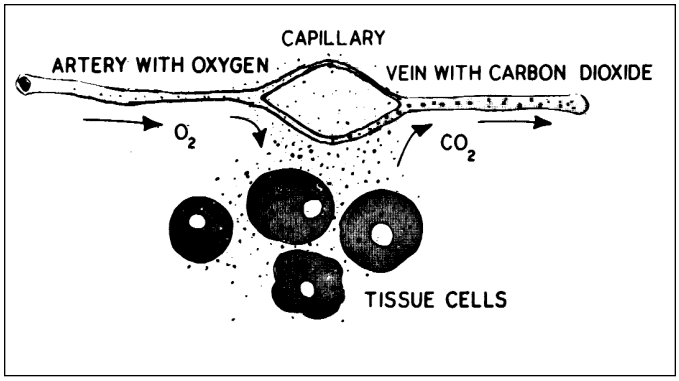

Figure 2–9. Exchange of oxygen and carbon dioxide between blood vessels, capillaries, and tissue cells. Oxygen passes from the blood to the capillaries to the tissue cells. Carbon dioxide passes from the tissue cells to the capillaries and into the blood. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 2. Chicago, IL, American Academy of Orthopaedic Surgeons, 1977.)

Pressure Changes

The basic principle underlying the movement of any gas is that it travels from an area of higher pressure to an area of lower pressure, or from a point of greater concentration of molecules to a point of lower concentration. This principle applies not only to the flow of air into and out of the lungs but also to the diffusion of oxygen and carbon dioxide through alveolar and capillary membranes. The respiratory muscles and the elasticity of the lungs make the necessary changes in the pressure gradient possible, so that air first flows into the air passages and then is expelled.

Atmospheric pressure is the pressure exerted against all parts of the body by the surrounding air. It averages 760 mm of mercury (760 mmHg) at sea level. Any pressure that falls below atmospheric pressure is called a negative pressure and represents a partial vacuum.

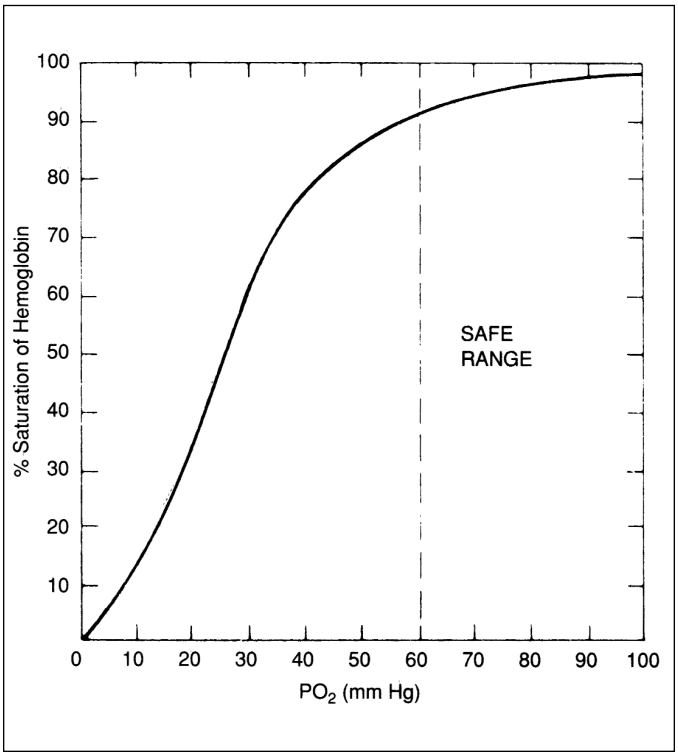

Figure 2–10. Percent saturation of hemoglobin with oxygen at various partial pressures is shown in the hemoglobin saturation curve. (Reprinted from *A Guide to Industrial Respiratory Protection,* NIOSH Publication No. 76–189, 1976.)

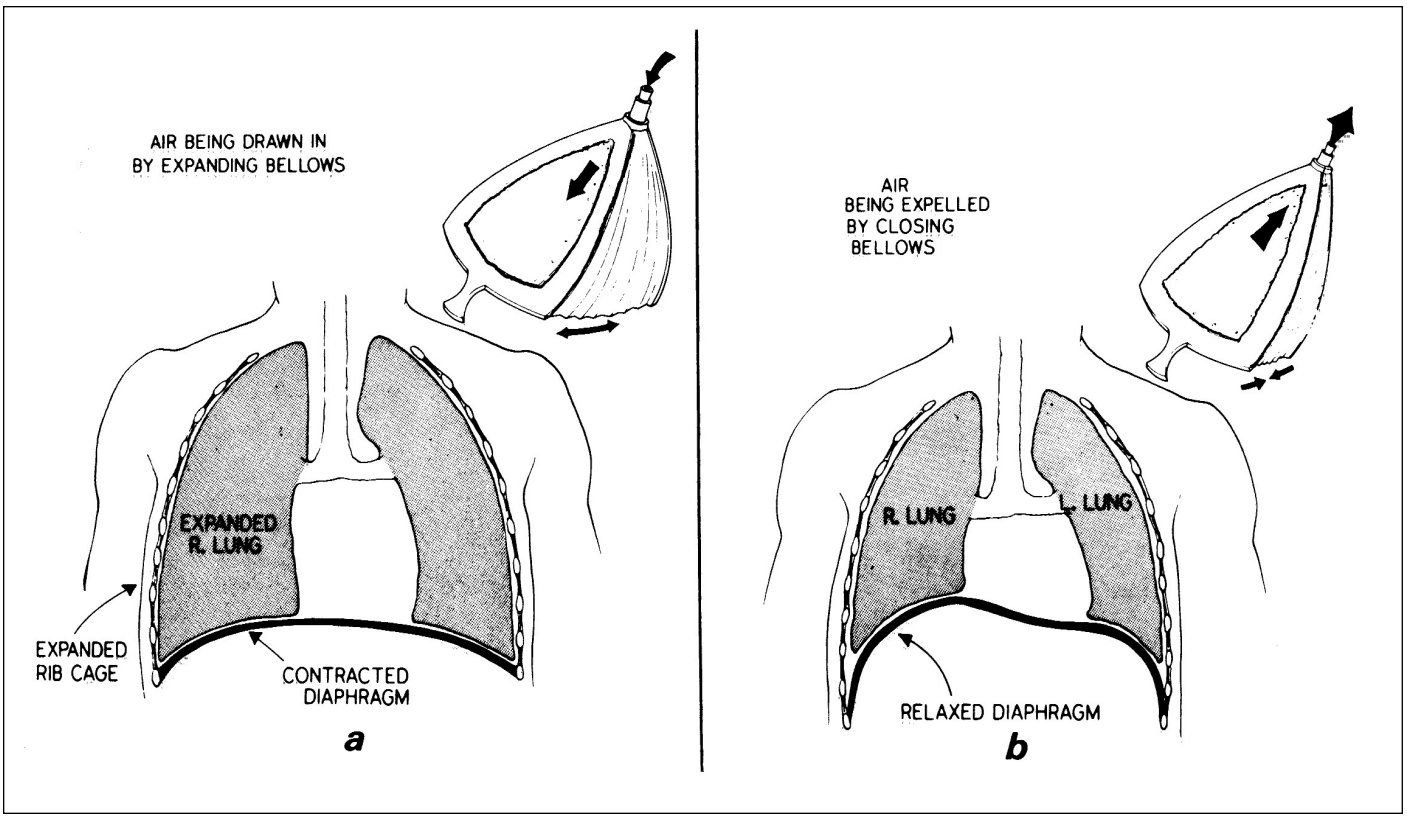

Figure 2–11. Inhalation is similar to the act of air entering a bellows. It occurs when the diaphragm contracts and the ribs expand. Exhalation is similar to the act of air leaving a bellows. It occurs when the diaphragm and ribs relax. (Reproduced with permission from *Emergency Care and Transportation of the Sick and Injured,* ed. 1. Chicago, IL, American Academy of Orthopaedic Surgeons, 1971.)

Intrapulmonic pressure is the pressure of air within the bronchial tree and the alveoli. During each respiratory cycle this pressure fluctuates below and above atmospheric pressure as air moves into and out of the lungs. Intrapulmonic pressure is below atmospheric pressure during inspiration, equal to atmospheric pressure at the end of inspiration, above atmospheric pressure during expiration, and again equal to atmospheric pressure at the end of expiration.

This series of changes in intrapulmonic pressure is repeated with each respiratory cycle. Whenever the size of the thoracic cavity remains constant for a few seconds, or in a position of rest, the intrapulmonic pressure is equal to atmospheric pressure.

Lungs have one way of filling themselves. Movement of the thoracic cage and the diaphragm permits air to enter the lungs. The thoracic cage is a semirigid bony case enclosed by muscle and skin. The diaphragm is a muscular partition separating the chest and abdominal cavities.

The chest cage can be compared to a bellows. The ribs maintain the shape of the chest bellows. The opening of the chest bellows is through the trachea. Air moves through the trachea to and from the lungs to fill and empty the air sacs (Figure 2–11). When a bellows is opened, the volume it can hold increases, causing a slight vacuum. This lowers the air pressure inside the bellows and causes the higher pressure outside the bellows to drive air through the opening, thereby filling the bellows.

When the air pressure inside equals the pressure outside, air stops moving into the bellows. Air will move from a high-pressure area to a low-pressure area until the pressure in both areas is equal. Therefore, as the bellows is closed, the pressure inside becomes higher than outside and air is expelled (Figure 2–11).

During inspiration (inhaling), the diaphragm and rib muscles contract. When the diaphragm contracts, it moves downward and enlarges the thoracic cavity from top to bottom. When the rib muscles contract, they raise the ribs. This enlarges the chest cavity (bellows) in all dimensions. This enlargement of the thoracic cavity reduces the pressure within the chest. The action is identical to that of opening a bellows. Air rushes into the lungs. Take a deep breath to see how the chest increases in size. This is the active muscular part of breathing.

During expiration (exhaling), the diaphragm and the rib muscles relax. As these muscles relax, the chest cavity decreases in size in all dimensions. As it does so, the air in the lungs is pressed into a smaller space, the pressure increases, and air is pushed out through the trachea. Decrease in size of the chest cavity after relaxation is accomplished largely by action of elastic tissue in the lung, which stretches for inhalation and recoils after muscular relaxation.

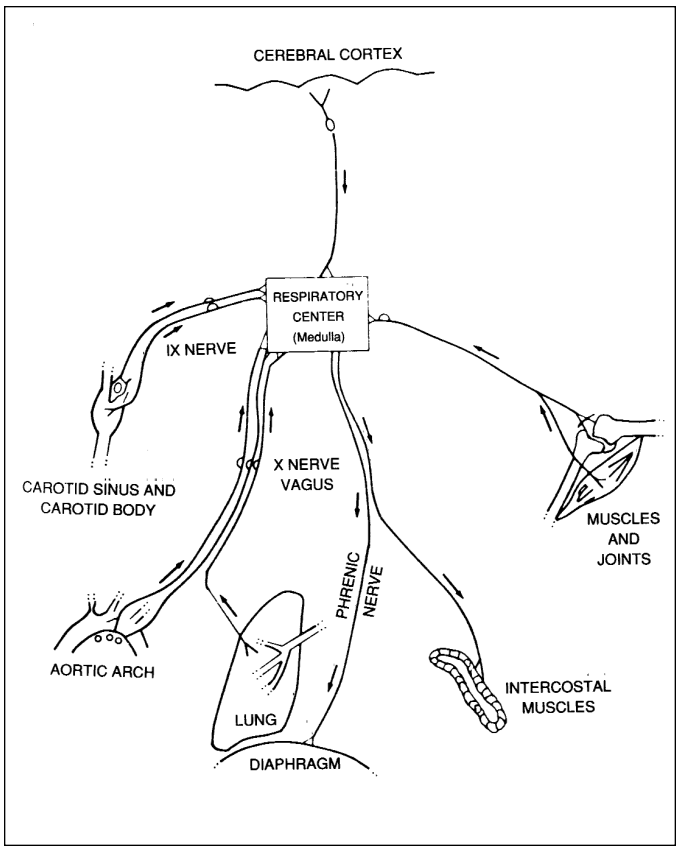

Figure 2–12. Normal rhythmic breathing is controlled by the requirement to ventilate the lungs to remove carbon dioxide as fast as it is produced by metabolic activity. The factors effective in controlling breathing are illustrated schematically. (Reprinted from Parker JF. *Bioastronautics,* 2nd ed. Washington, DC: National Aeronautics and Space Administration, 1973.)

Control of Breathing

Breathing is controlled by a series of respiratory centers in the nervous system. One center is in the medulla, the part of the brain at the top of the spinal cord (Figure 2–12).

Respiratory Center

Nerve impulses originating in the motor areas of the cerebral cortex and traveling to the respiratory center enable us to consciously alter the rate and the depth of breathing. For example, during speaking or singing, breath control is very important.

You can hold your breath voluntarily for a short period of time. However, voluntary control is limited, and the respiratory center will ignore messages from the cortex when breathing is necessary to meet the body's basic needs.

Carbon Dioxide

Breathing action can be triggered by the respiratory centers when the amount of carbon dioxide in the blood increases or when the oxygen level of the blood decreases.

If you hold your breath, carbon dioxide accumulates in the blood until, finally, it so strongly stimulates the respiratory control center of the brain that you are forced to breathe again. The length of time the breath can be held varies from 25 to 75 seconds; some people can hold their breath even longer.

Rate

Even in a relaxed state, you breathe in and out 10–14 times a minute, with each breath lasting 4–6 seconds. In a minute, 9–12 pt (4.3–5.7 L) of air are taken in. The fact is that the body has small reserves of oxygen; all of it is consumed within less than half a minute after the start of vigorous exertion. With such exertion, the need for air increases many times so that the breathing rate may speed up to one breath per second and a total intake of 31 gal (120 L) of air per minute.

In a normal day, you breathe some 3,300 gal (12,491 L) of air—enough to occupy a space of about 8 ft^3; in a lifetime, you will consume enough to occupy 13 million ft^3 (368,120 m^3) of space.

Lung Volumes and Capacities

For descriptive convenience the total capacity of the lung at full inspiration is divided into several functional subdivisions. These are illustrated in Figure 2–13.

The four primary lung volumes that do not overlap are as follows:

- ➢ Tidal volume (TV)—the volume of gas inspired or expired during each respiratory cycle
- ➢ Inspiratory reserve volume (IRV)—the maximal volume that can be forcibly inspired following a normal inspiration (from the end-inspiratory position)
- ➢ Expiratory reserve volume (ERV)—the maximum amount of air that can be forcibly expired following a normal expiration
- ➢ Residual volume (RV)—the amount of air remaining in the lungs following a maximum expiratory effort

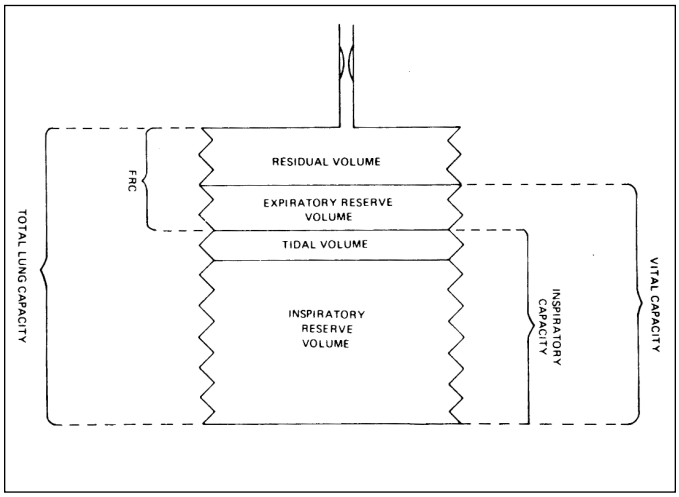

Figure 2–13. Inspiratory capacity and tidal capacity. (Reprinted from Parker JF. *Bioastronautics,* 2nd ed. Washington, DC: National Aeronautics and Space Administration, 1973.)

Each of the four following capacities includes two or more of the primary volumes:

- ➢ Total lung capacity (TLC)—the sum of all four of the primary lung volumes
- ➢ Inspiratory capacity (IC)—the maximum volume by which the lung can be increased by a maximum inspiratory effort from midposition
- ➢ Vital capacity (VC)—the maximum amount of air that can be exhaled from the lungs after a maximum inspiration (the sum of the inspiratory reserve volume, tidal volume, and expiratory reserve volume)
- ➢ Functional residual capacity (FRC)—the normal volume at the end of passive exhalation; that is, the gas volume that normally remains in the lung and functions as the residual capacity

In an ordinary inhalation the first air to enter the lungs is the air that was in the bronchi, throat, and nose—air that had left the lungs in the previous expiration but had not been pushed out as far as the outside world. Then, after an inspiration is complete, some of the fresh air that entered through the nostrils remains in the air passages; here it is useless, and is expired again before it can get to the lungs. The dead space represents the air passages between the nostrils and lungs. Fresh air actually entering the lungs with each breath may amount to no more than 21.4 $in.^3$ (350 cm^3). This represents only 1/18 of the lungs' total capacity and is called the tidal volume.

The partial replacement of the air in the lungs (alveolar air) by the shallow breathing we normally engage in is sufficient for ordinary purposes. We are quite capable of taking a deep inhalation of air as well, forcing far more into the lungs than would ordinarily enter. After about 30.5 $in.^3$ (500 cm^3) of air have been inhaled in a normal quiet breath, an additional 153 $in.^3$ (2,500 cm^3) can be sucked in. On the other hand, you can force 42.7 $in.^3$ (7,000 cm^3) of additional air out of the lungs after an ordinary quiet expiration is completed. By forcing all possible air out of the lungs and then drawing in the deepest possible breath, you can bring well over 1.7 ft^3 (4,000 cm^3) of new air into the lungs in one breath. This is the vital capacity.

Even with the utmost straining, the lungs cannot be completely emptied of air. After the last bit of breath has been forced out, about 73 $in.^3$ (1,200 cm^3) remain. This is the residual volume and is a measure of the necessary inefficiency of the lungs.

Vital lung capacity is measured by inhaling as deeply as possible and blowing out as much as possible into a spirometer. The quantity of expelled air varies with body size and age. A medium-sized man may have a vital capacity of 1.7–1.9 ft^3 (4,000–4,500 cm^3) between the ages of 20 and 40 years. However, as the elasticity of tissues decreases with age, the vital capacity diminishes and may be as much as 20 percent less at age 60 and 40 percent less at age 75.

Spirometry means measurement of air—the ventilatory capacity of the lungs. The spirometer achieves this by measuring volumes of air and relating them to time.

Change in the ability to move air into and out of the lungs in a normal manner results in what is called either obstructive or restrictive ventilatory defect, or a combination of the two. In diseases associated with an obstructive ventilatory defect, such as asthma or chronic obstructive pulmonary disease (COPD), there is reduction of air flow rates during and a prolongation of expiration. In diseases causing a restrictive ventilatory defect, such as the pneumoconioses (e.g., asbestosis, silicosis), there is a decreased ability to take a deep breath due to scarred (i.e., stiffer) lungs.

Forced vital capacity (FVC) is the maximal volume of air that can be exhaled forcefully after a maximal inspiration. For all practical purposes, the VC without forced effort and the FVC are identical in most people.

In the early detection of pneumoconiosis, the FVC is of variable use. In asbestosis, the FVC is regarded as a relatively sensitive indicator of early disease and may be impaired before there are radiographic abnormalities. Conversely, x-ray changes may be evident in silicosis while the FVC is still normal.

Forced expiratory volume in 1 second (s) (FEV_1) is the volume of air that can be forcibly expelled during the first second of expiration. With an obstructive ventilatory defect, the FEV_1 is decreased while the FVC is relatively preserved, leading to a decreased FEV_1/FVC ratio.

Forced expiratory flow (FEF) during the middle half of the FVC ($FEF_{25–75\%}$) can be defined as the average rate of flow during the middle two quarters of the forced expiratory effort. Compared with FEV_1, it may be more sensitive in detecting early airway obstruction and tends to reflect changes in airways less than 2 mm in diameter. Airborne substances are thought to exert their initial deleterious effects in these smaller bronchi and bronchioles. Smoking one cigarette can lower the $FEF_{25–75\%}$ for several hours.

Peak expiratory flow (PEF) is another measure of expiratory flow. PEF is the peak of the expiratory flow volume curve. The peak expiratory flow rate is the rate of maximal expiratory flow. The development of portable peak flow meters that directly measure flow rates has allowed workers to measure their lung function during and away from work. It has the advantages of sensitivity to early obstructive changes and ease of measurement.

HAZARDS

Let's look at some of the unhealthy conditions to which the lung is subject, the associated terminology, and some typical hazardous substances.

The membrane lining of the nasal passages can be affected by a number of causes. The resultant condition is called *rhinitis.* Inflammation in the larynx is called laryngitis; that of the bronchial tubes is called *bronchitis.* Constriction of the tube muscles in response to irritation, allergy, or other stimulus is called *asthma.*

In the lungs, a number of conditions can develop:

- ➢ *Atelectasis* means incomplete expansion of the lungs. It is caused by occlusion of a bronchus, perhaps by a plug of heavy mucus, with subsequent absorption of the air, or by external compression, as from a pleural effusion or a tumor. The atelectatic portion of the lung will allow blood to pass through without adding oxygen or removing carbon dioxide.
- ➢ The term *emphysema* derives from Greek words meaning *overinflated.* The overinflated structures are the alveoli. Cigarettte smoke and some occupational agents (e.g., coal dust, cadmium fumes) can cause destruction of alveolar walls that leads to emphysema. Chronic inflammation of the small and large airways (bronchiolitis, bronchitis) is also often present in patients with emphysema. The inflamed airways tend to become narrowed due to increased mucus production, swelling of the lining membrane, and enlargement (hypertrophy) of the surrounding muscle. Air flows into the alveoli easily but cannot flow out easily because of the narrowed diameter of the bronchioles. The patient can breathe in, but cannot breathe out efficiently; this leaves too much CO_2 in the lungs. As pressure builds up in the air cells, their thin walls are stretched to the point of rupture, so several air spaces communicate and the area of surfaces where gas exchange takes place is decreased.
- ➢ *Pleurisy* is caused when the outer lung lining (the visceral pleura) and the chest cavity's inner lining (the parietal pleura) lose their lubricating properties. The resultant friction causes irritation and pain. The thin, glistening layer of pleura that is inseparably bound to the lung has no pain fibers, but the opposing pleura is richly supplied. Normally the pleural layers glide over each other on a thin film of lubricating fluid. Disease may cause the pleura to become inflamed and adherent, or fluid may accumulate in the pleural space, separating the layers.
- ➢ *Pneumonitis* is any inflammation of the lung. It is essentially equivalent to the term *pneumonia,* which is usually reserved for infectious inflammation.
- ➢ *Bronchitis* is inflammation of the lining of the bronchial tubes. Chronic bronchitis means that the infection is persistent.
- ➢ *Pneumoconiosis* (dusty lung) is a general word for various pulmonary manifestations of dust inhalation, whether the dust is harmful or not. Two common forms of pneumoconiosis are silicosis and asbestosis. The typical pathological condition in harmful pneumoconiosis is the existence of fibrotic (scar) tissue in the alveolar sacs or at lymph nodes in the lungs. This fibrotic tissue, caused by some dust particles, reduces the efficiency of the lungs by making them less resilient and by reducing the effective working surface for gaseous exchange.

The fate of an inhaled air contaminant depends on its size, solubility, and chemical reactivity. As noted previously, larger particles tend to get deposited in the upper airways, trachea, and bronchi, while smaller particles (i.e., <3 μm in diameter) tend to deposit in the smaller airways and alveoli (the so-called deep lung). More soluble, reactive substances get absorbed onto the moist mucous membranes of the upper airways, trachea, and larger bronchi, leading to irritation and inflammation of these structures. Less soluble, reactive gases cause less irritation of the mucous membranes so that they cause less "warning" irritation of the mucous membranes. If any reactive substance is inhaled into the deep lung, then inflammation of the alveoli, or pneumonitis, can occur. If the chemical injury to the alveoli is severe enough, flooding of the alveoli with inflammatory material can occur, known as pulmonary edema. When there is pulmonary edema, gas exchange becomes markedly impaired.

Most of the particles that reach the deep lung (alveoli) are engulfed by cellls called macrophages (literally "big eaters") that migrate proximally to the airways and are either expectorated or swallowed or may enter the interstitial tissues. Once in the deep lung, however, chemical components in particles or in the vapor state can be absorbed into the bloodstream.

Inhaled contaminants that adversely affect the lungs fall into three general categories:

- ➢ Aerosols and dusts, which, when deposited in the lungs, may produce tissue reaction and/or disease
- ➢ Toxic gases that may produce direct tissue injury
- ➢ Toxic aerosols or gases that do not affect the lung tissue, but are passed from the lung into the bloodstream, where they are carried to other organs or have adverse effects on the oxygen-carrying capacity of the bloodstream (see Chapter 6, Industrial Toxicology)

Potential health hazards from dust occur on three levels. The inhalation of sufficient quantities of dust, regardless of its chemical composition, can cause a person to choke or cough; it can also accumulate in the lungs. Depending on its chemical composition, dust can cause an allergic or sensitization reaction in the respiratory tract. Depending on both its size and chemical composition, dust can, by physical irritation or chemical action, damage the airway and/or lung.

Fibrosis can be produced by certain insoluble and relatively inert fibrous (e.g., asbestos) and nonfibrous (e.g., silica) solid particulates found in industry. It is now thought that one of the prerequisites for particulate-induced bronchogenic carcinoma may be the insolubility of the particulate in the fluids and tissues of the respiratory tract. More insoluble particulates can reside in the lung long enough to induce tumors. A category of aerosol hazard, *bioaerosols,* includes certain bacteria and fungi that can cause an allergic-type inflammatory disease of the lungs called hypersensitivity pneumonitis. These microorganisms are found on moldy vegetative material such as silage, compost, and sugar cane.

Some of the reactive industrial gases and vapors of high solubility that can produce immediate irritation and inflammation of the entire respiratory tract include ammonia, hydrogen fluoride, and sulfur dioxide. Less soluble gases, such as nitrogen dioxide, phosgene, and ozone primarily

affect the deep lung (the bronchioles and the adjacent alveolar spaces) where they may produce pulmonary edema within a few hours.

Carbon monoxide (CO) is a toxic gas that is transferred from the lungs into the bloodstream but does not damage the lungs. Carbon monoxide passes through the alveolar walls into the blood, where it binds hemoglobin so it cannot accept oxygen, thus causing oxygen starvation.

Many metal oxides of submicron particle size (called fume) produce both immediate and long-term effects; the latter can occur in organs and tissues remote from the site of entry. For example, cadmium oxide fume inhaled at concentrations well above the Threshold Limit Value (TLV®) may produce immediate pulmonary edema that can be fatal; in addition, inhalation for many years of the fume at concentrations of a few multiples of the TLV can result in eventual renal injury and pulmonary emphysema.

Individual susceptibility to respiratory toxins is difficult to assess. In the occupational setting, workers exposed to the same environment for equal periods of time may develop different degrees of pulmonary disease. This can be due to the variation of the rate of clearance from the lung, the effect of cigarette smoking, coexistent pulmonary disease, and genetic factors.

NATURAL DEFENSES

The respiratory system has a rather complete set of mechanisms for shrugging off insults: the warming and humidifying effects of the nasal and throat passages (as defenses against very cold or overly dry air), the mucous lining, and physical impaction on the branching respiratory tree.

Because the mucous lining plays an important role in the cleansing of aerosols from the lungs, it deserves closer inspection. Cells in the trachea and bronchi produce mucus that is constantly being carried toward the mouth by tiny hairlike projections, called cilia, waving in synchrony. This moving blanket acts as a vehicle to carry foreign substances up and out of the system to the throat, where they can be expectorated or swallowed.

In a healthy lung, aerosols that get into a bronchiole can be carried back out of the system in a matter of hours. Given adequate recovery time (about 16 hours) after an eight-hour exposure to dust, the healthy lung can thus cleanse itself.

Other defense mechanisms include muscular contraction of the bronchial tubes upon irritation—this reaction restricts the airflow and thus minimizes intake of the irritating substance—and the cough and sneeze, which tend to rid the upper respiratory tract of irritants.

Thus far we have discussed only the defenses of the airways leading to the alveoli. In general, only very fine particles and gases reach the alveolar sacs. The larger the particle, the sooner it will be deposited through impaction or gravity on the lining of the airway tubes leading to the sacs.

In the case of gases, the concentration that reaches the alveolar sacs will be nearly the same as the concentration in the air breathed. With aerosols, this is not the case. Large particles, more than 10 μm, will be deposited long before they reach the alveoli, through gravity and impaction. Only the smaller particles will reach the alveoli. In the alveoli, Brownian movement of the particles results in deposition by diffusion.

Because only the small (fine) particles are likely to reach the alveoli in great quantities, and because the alveoli are the most important area in the lungs, it is clear that fine aerosols are potentially more harmful than larger aerosols. What happens to fine particles that do reach the alveolar sacs?

Particles deposited in the alveoli will be scavenged by macrophages, which are mobile white blood cells capable of ingesting particles. Once laden with foreign matter, these cells can do the following:

- ➢ migrate to the bronchioles, where the mucous lining carries them out of the system
- ➢ pass through the alveolar membrane into the lymph vessels associated with the blood capillaries
- ➢ be destroyed (if the contaminant is cytotoxic) and break up, releasing the particles back into the alveolar sac

If the particles are not removed by these means, they can form a deposit in and around the alveoli. Such deposits may or may not affect the health of the lungs over time.

All of the defense mechanisms are subject to some deterioration and slowing down with age or ill health. Thus, an older worker's lungs will not be cleaned as quickly or efficiently as those of a younger person. Also, some contaminants may impede the defense mechanisms themselves, increasing the rate of retention of the contaminant in the lungs.

AMA GUIDES FOR EVALUATING IMPAIRMENT

This section on determining the percent impairment is adapted from the American Medical Association's (AMA) *Guides to the Evaluation of Permanent Impairment* and is included to assist health and safety professionals in interpreting and understanding medical reports of workers' compensation cases.

This AMA publication assists physicians in evaluating permanent impairment of the respiratory system and the effect such impairment has on a person's ability to perform the activities of daily life. Permanent impairment of the respiratory system is not necessarily a static condition. A changing process can be present, so that it may be desirable to reevaluate the patient's impairment at appropriate intervals.

The measurable degree of dysfunction of the respiratory system does not necessarily parallel either the extent and severity of the anatomic changes of the lungs or the patient's own account of difficulties in carrying out the activities of daily life. Among the reasons for this phenomenon are the large pulmonary reserves normally present, existence of disease in other systems (particularly the cardiovascular system), wide variation in certain physiological measurements in normal individuals, and the patient's emotional response to respiratory disease or injury.

Many tests of pulmonary function have value and interest as guides to therapy and prognosis. For most patients, however, most of these are neither practical nor necessary for assignment to a particular class of impairment. Judicious interpretation of the results of ventilatory function tests and diffusion studies, combined with the clinical impression gained from weighing all the information gathered, should permit a physician to place the patient in the proper class of impairment.

Rating of Impairment

The classification of respiratory impairment is based primarily on spirometric tests of pulmonary function and diffusing capacity for carbon monoxide (D_{CO}).

Procedures useful in evaluating impairment of the respiratory system include but are not limited to complete history and physical examination with special reference to cardiopulmonary symptoms and signs; chest roentgenography (posteroanterior, PA) in full inspiration, lateral, and other procedures as indicated; hematocrit or hemoglobin determination; electrocardiogram, FEV_1, FVC, and D_{CO}; and other tests, such as blood gas and pulmonary exercise studies, as indicated.

Tests of Pulmonary Function—Ventilation

The tests of ventilatory function have certain limitations:

- ➢ They require maximal voluntary effort by the patient, who may be unable or reluctant to perform the tests as well as ventilatory capacity permits. For example, the performance may be affected by the patient's lack of understanding of the test; state of physical training; fear of cough, chest pain, hemoptysis, or worsening of dyspnea; motivation and cooperation; the effects of other illness, particularly heart disease; and the effects of certain temporary factors on the day of the test, such as the presence of a respiratory infection or bronchospasm.
- ➢ The results of these tests vary considerably among normal people of the same sex, age, and height.
- ➢ Infrequently, significant impairment of respiratory function can exist even though the patient can perform the tests of ventilatory function normally; that is, the bellows action of the lungs and thorax is normal, but there are abnormalities of pulmonary circulation or gas exchange that give rise to the impairment and necessitate other evaluation procedures.

Various types of spirometers are available that give a permanent record and that readily permit measurement of the FEV_1 and the FVC. These tests can be understood by patients after a short explanation and instruction period, but most patients must be encouraged to put forth their best effort. The FEV_1 and FVC should each be administered at least three times, with the best test result considered most representative of the patient's ability. The test should not be considered valid unless the best two curves agree within five percent.

If the forced expiratory volume test is interpreted as showing airflow obstruction, the test might be repeated 10–15 min after the patient has inhaled a nebulized bronchodilator. If there is at least 12-percent improvement in the performance of the test, the possible reversibility of the airway obstruction and, incidentally, the presumed efficiency of bronchodilator therapy are established. The patient's best test results before or after bronchodilation should be used in determining the degree of impairment.

Results of tests of ventilatory function should be expressed both in liters or liters per minute and as a percentage of the predicted normal. The FVC as a percentage of the predicted normal is taken as a measure of restrictive impairment. The ratio of actual FEV_1 to actual FVC is a criterion for diagnosing obstructive impairment, but the value of measured FEV_1 either by itself or as a percentage of predicted FEV_1 is considered the best measure of severity. Determination of exercise capacity and arterial blood-gas determinations are useful when a patient's symptoms do not correlate

Table 2–A. ***Terminology of Certain Pulmonary Function Measurements***

Terms Used	*Symbol*	*Description*	*Remarks*
Forced vital capacity	FVC	The largest volume of air measured on complete expiration after the deepest inspiration performed with expiration as forceful and rapid as possible (in liters).	This value should be ≥ the lower 95% confidence interval of the predicted value. A lower value suggests the presence of either an obstructive or restrictive ventilatory defect. If the FEV_1/FVC is >70%, then a restrictive defect is likely present.
Forced expiratory volume in one second	FEV_1	Volume of air exhaled during the performance of a forced expiratory maneuver in the first second (in liters).	
One-second forced expiratory volume expressed as a percentage of FVC	$\frac{FEV_1}{FVC} \times 100$	The observed FEV_1 expressed as a percentage of the observed FVC.	This value normally should exceed 70%. A lower value suggests the presence of some degree of obstructive airway disease.
Diffusing capacity for carbon monoxide	D_{CO}	The rate at which CO is transferred from the lungs to the blood (in mL/min/mmHg).	

well with spirometric studies. Diffusing capacity of carbon monoxide (single-breath D_{CO}) is available in most pulmonary function laboratories. It detects interference with transfer of gases across the alveolar membrane, as may occur in emphysema or interstitial fibrosis. Tables for "normal" values of FVC, FEV_1, FEV_1/FVC, and D_{CO} are given in the AMA *Guides to the Evaluation of Permanent Impairment.*

Quantitative exercise capacity measurements can be done using a treadmill or stationary bicycle. The primary exercise measurement used in respiratory impairment rating is the maximal oxygen consumption ($\dot{V}o_2max$). A patient's $\dot{V}o_2max$ provides a good estimate of the maximum workload that he/she can tolerate.

Determinations of partial pressures of oxygen and carbon dioxide in arterial blood, particularly before and after exercise, can be useful in certain cases. These measurements require arterial puncture, so they are not suitable for routine evaluation.

Other measurements of pulmonary function are available in specialized laboratories, but they are not sufficiently standardized for evaluation of impairment.

The *AMA Guides* classify respiratory impairment into four classes—none, mild, moderate, and severe—based on FVC, FEV_1, FEV_1/FVC, and D_{CO} or $\dot{V}o_2max$. Special criteria independent of pulmonary function are assigned to asthma, hypersensitivity pneumonitis, pneumoconiosis, or lung cancer. The 5th edition of the *AMA Guides* includes a new classification of impairment due to asthma that involves three different parameters: post-bronchodilator FEV_1, percent change in FEV_1 post-bronchodilator or degree of methacholine responsiveness (a measure of nonspecific airway hyperresponsiveness to noxious stimuli), and minimum medication needed to provide optimal control of the disease.

SUMMARY

The *nose* is an external organ lined by an extensive mucous membrane that warms, moistens, and filters inhaled air. It is the organ of smell.

The *pharynx* is located at the back of the nose and mouth, and above the larynx. It is a cylindrical tube that allows passage of food and air.

The *larynx, or* voice box, is an anterior structure in the neck. Its cartilaginous walls hold it open during inspiration and expiration.

The *trachea and bronchi* are airways lined with ciliated mucous membrane and have rings of cartilage to maintain patency. At midsternal level the trachea divides into two bronchi, one going to each lung. The left bronchus is longer and more horizontal than the right to accommodate the heart; consequently, inhaled foreign bodies find their way more easily into the right bronchus. These structures are the main sensory area for the initiation of the cough reflex. Their ciliated linings sweep mucus upward to the throat.

The *lungs* are two spongy cone-shaped organs that occupy the major portion of the thoracic cavity. The space between them is called the mediastinum, and contains the heart, blood vessels, and all tubes passing to and from the abdomen. The lungs are made up of acini or terminal lung units that contain a terminal bronchiole to which clusters of alveoli are connected by respiratory bronchioles.

The *alveoli* are clustered at the ends of the bronchioles like bunches of grapes. They have a rich blood supply from the pulmonary arteries, allowing close contact of blood and air, thus permitting the interchange of oxygen into the blood and carbon dioxide into the air.

The bronchioles, alveoli, and blood vessels are supported by elastic connective tissue, which, with lymphatic vessels, glands, and nerves, form the substance or interstitium of the lungs.

The vital capacity of the lungs is 3–4 L of air, but only half a liter is exchanged with each quiet respiration. As well as the gaseous exchange in the lungs, heat and moisture are lost from the body.

Spontaneous inspiratory nervous impulses arise from a center in the brain stem. This center is influenced by stimuli from many chemical and mechanical receptors. The stimulus for expiration is of a nervous origin and arises from stretching of the nerve endings in the alveolar wall. This stimulus cuts out the impulses that produced inspiration; by elastic recoil and relaxation of muscle, expiration is produced.

Human lungs are size-selective dust collectors. Only relatively small particles, generally those less than 2.5–3 μm in diameter, reach the alveolar spaces. The lungs have a very large surface, 300–1,000 ft^2 (28– 92 m^2) of very delicate tissue. This surface is exposed to contaminants in the air breathed. The lungs have good defenses against particulates; when unimpaired, these clearance mechanisms remove about 99 percent of the insoluble dust deposited in the lungs.

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Chapter 3

The Skin and Occupational Dermatoses

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Portions of this chapter in the first and second editions of this book were written by Julian B. Olishifsky and Larry L. Hipp.

The skin is the largest organ of the body. Its surface area is about 2 m^2 and in most places it is no more than 2 mm thick, yet its mass exceeds that of all other organs. Skin is a tough, flexible cover and is the first body barrier to make contact with a wide variety of industrial hazards. The skin is subject to attack from heat, cold, moisture, radiation, bacteria, fungi, and penetrating objects. Health and safety professionals should have a basic understanding of the anatomy, physiology, and defense mechanisms of the skin before recommending proper control measures.

The skin performs a number of important functions. Among these are protecting the body from invasion by microorganisms (fungi, bacteria, etc.), injury to vital internal organs, the rays of the sun, and the loss of moisture. The skin is also an organ of sensory perception; the sensations of pain, touch, itch, pressure, heat, cold, and warmth may be elicited in human skin.

Temperature regulation is yet another job performed by the skin. Blood vessels dilate (widen) when the body needs to lose heat or constrict (narrow) when the body must reduce the amount of heat loss through the skin.

When the surrounding air is comparatively warm, the skin is cooled by evaporation of moisture excreted by the sweat glands. There are between 2 and 3 million sweat glands over the surface of the body, excluding mucous membranes. The greatest concentration of sweat glands is on the palms of the hands and the soles of the feet. Their function depends on an intact nerve supply. Thermoregulatory sweating is controlled by a heat regulator in the brain. Emotions stimulate sweating primarily on the palms and soles.

The surface of the skin may look smooth, but if it is examined under a magnifying glass, countless ridges and valleys can be seen in which the many small openings of pores, hair follicles, and sweat glands are found (Figure 3–1). There are also different patterns of skin texture; compare the palm of the hand with the back of the hand, for example. The skin generally is soft, flexible, and elastic, particularly in young people.

A number of predisposing factors interact to determine the degree to which a person's skin responds to chemical, physical, and biological insults. These include type of skin (pigmentation, dryness, amount of hair), age, sex, season, previous skin diseases, allergies, and personal hygiene.

A worker's skin is very vulnerable to occupational hazards. Surveys indicate that dermatological conditions other than injuries are the second most common cause of all occupational diseases, accounting for 13 percent of all cases reported to the Bureau of Labor Statistics in 1997. Occupational skin disease is underreported and results in considerable lost time from work.

Although most occupational skin disorders are treated by primary care and occupational physicians, dermatologists are often consulted. Dermatology is the branch of medicine concerned with the diagnosis, treatment including surgery, and prevention of diseases of the skin, hair, and nails. Some dermatologists have had special training in occupational skin disorders.

Some disorders that are visible in the skin do not arise primarily in the skin but in other organs. Thus, the skin is an early warning system and its examination is very important in physical diagnosis, occasionally furnishing the first clue to identification of systemic diseases.

ANATOMY

Three distinct layers of tissue make up the skin; from the surface downward, they are the epidermis, the dermis, and the subcutaneous layer.

The thickness of the skin varies from 0.5 mm on the eyelid (the dermis is thinnest here) to 3–4 mm on the palms of the hands and soles of the feet (the epidermis is thickest here). Skin is also relatively thin in the skin folds: the axillae (armpits), under the breasts, the groin, and between the fingers and toes.

Epidermis

The top layer of the epidermis is composed of dead cells called the horny or keratin layer or the stratum corneum. This layer resists chemical attack fairly well, with the notable exception of alkali. It serves as the chief rate-limiting barrier against absorption of water and aqueous solutions, but offers little protection against lipid-soluble materials (such as organic solvents) or gases.

The horny layer gradually flakes off, or soaks off when wet. It is constantly being replaced by cells pushed toward the surface as new cells are formed in the deeper, germinative layer of the epidermis. This regenerative and sloughing characteristic serves to some extent as a protection against chemicals and microorganisms.

This constant shedding of flaky material goes mostly unnoticed unless a person has dandruff or must peel off insensate skin patches after a sunburn. Brisk rubbing with a towel peels off little rolls of material composed of dead outer skin cells that are never missed.

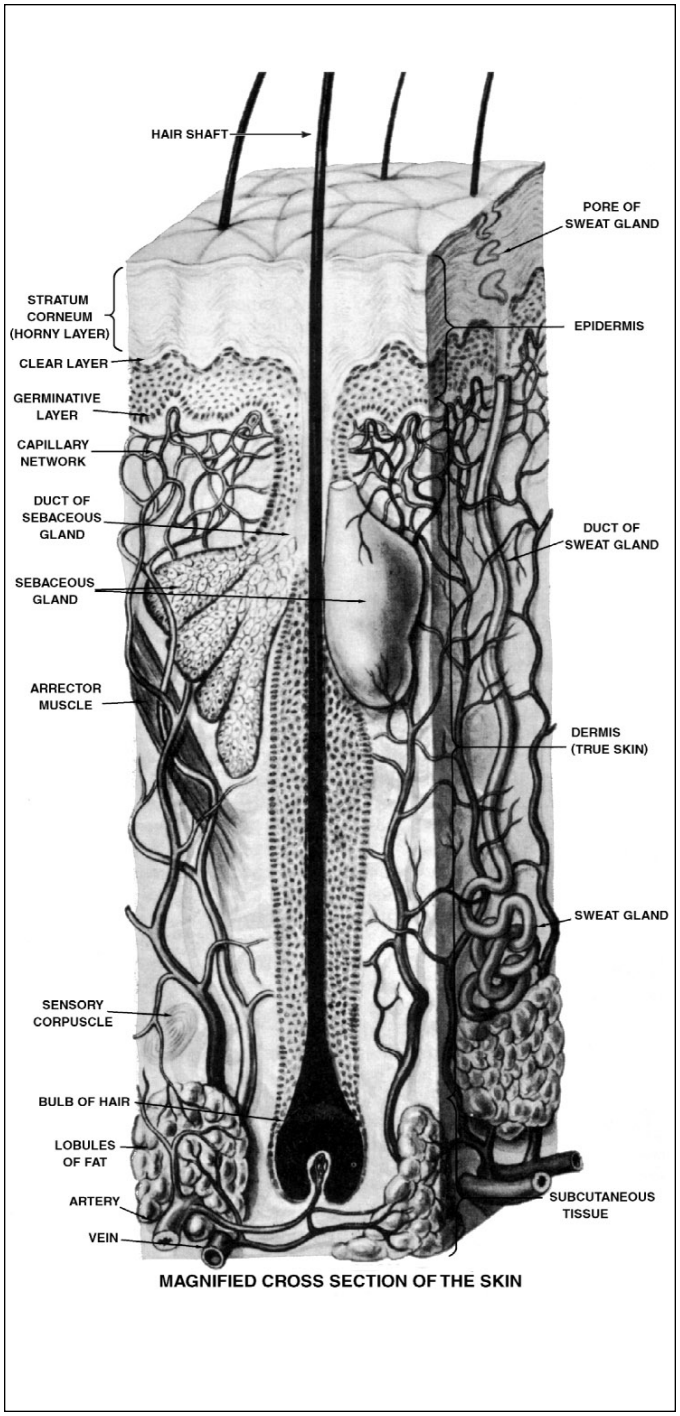

Figure 3–1. Magnified cross section of the skin. (Reprinted with permission of the AMA. *Today's Health Guide.* Chicago: AMA, 1965.)

There are three cell types in the epidermis:

- ➢ Keratinocytes, which make up the bulk of the epidermis, form from below and move up to become dead horny cells.
- ➢ Melanocytes, or pigment-forming cells, synthesize melanin (pigment) granules, which are then transferred to keratinocytes. The amount of melanin in keratinocytes determines the degree of pigmentation of skin

and hair. The absolute number of melanocytes in human skin is the same for all races. Differences in coloration among races result from differences in the number, size, degree of pigment formation, distribution, and rate of degradation of pigment granules within keratinocytes. Melanin proliferates under stimulus of certain wavelengths of sunlight and becomes visible as suntan or freckles. Moles are growths that contain melanin. Some people with little or no pigment in their skin have albinism, an inherited abnormality in which melanin (pigment) production is decreased. Vitiligo is a more common disorder in which loss of melanocytes also results in areas of cutaneous pigment loss. Some chemicals, such as phenolic germicides, can destroy pigment after occupational or environmental exposure.

➢ Langerhans' cells, located in the mid-epidermis, account for a relatively small percentage of all epidermal cells and play an important role in various immune processes, especially allergic contact dermatitis. Although the epidermis is an active tissue, it is not richly supplied with blood because blood vessels are absent. The blood supply to the epidermis is through the candelabra pattern of blood vessels in the upper dermal papillae (Figure 3–1).

The epidermis is thin enough that the nerve endings (Merkel cells) in the dermis are sufficiently close to the surface to supply the fine sense of touch. Some of this sensation is lost where areas of the skin are chronically subjected to friction, resulting in subsequent thickening of the epidermis that provides protection in the form of a callus.

Thus, the soles of the feet are commonly callused among those who habitually walk barefoot, as are the palms of the hands of those who do heavy work.

Dermis

Beneath the epidermis is the dermis, which is much thicker than the overlying epidermis, in most locations. It contains connective tissue composed of collagen elastic fibers and ground substance, is strong and elastic, and is the part of animal skins that makes leather when tanned. It is laced with blood vessels, nerve fibers, and receptor organs (for sensations of touch, pain, heat, and cold), and contains muscular elements, hair follicles, and oil and sweat glands (see Figure 3–1).

The dermis is tough and resilient, and is the main natural protection against trauma. When injured, it can form new tissue—a scar—to repair itself.

The top of the dermis is made up of a layer of tiny cone-shaped objects, called papillae. Thousands of papillae are scattered over the body. They are more numerous in areas such as the fingertips, where the skin appears to be more sensitive. Nerve fibers and special nerve endings are found in many of the papillae. As a result, the sense of touch is best developed in areas where papillae with nerve endings are most abundant.

The papillary layer fits snugly against the outer layer of skin, the epidermis, which has ridges corresponding to those of the papillae. The ridges prevent the skin layers from slipping against one another.

The ridges on the surfaces of the fingertips form the whorls, loops, and arches that make up fingerprints; dermatoglyphics is the study of the patterns of the ridges of the skin. Similar ridges appear on the soles of the feet. Because it is unlikely that two people will have the same pattern of ridges, fingertip patterns are used by the police to identify individuals.

The larger component of the dermis (reticular dermis) extends from the base of the papillary dermis to the subcutaneous fat. Muscle fibers are commonly seen in the reticular dermis on the face and neck.

Subcutaneous Layer

Beneath the dermis is a layer of subcutaneous tissue with fatty and resilient elements that cushions and insulates the skin above it. The distinguishing feature of the subcutaneous layer is the presence of fat. Also present are the lower parts of some eccrine and apocrine sweat glands and hairs, as well as hairs, nerves, blood and lymphatic vessels and cells, and fibrous partitions composed of collagen, elastic tissue, and reticulum. This layer links the dermis with tissue covering the muscles and bones.

Loss of subcutaneous fat and softer parts of the skin removes bouncy supporting material, and because the external skin does not shrink at the same rate, it tends to collapse and become enfolded in wrinkles.

Glands in the Skin

Two main types of glands are located in the dermis. One, already mentioned, is the sweat gland. Under the microscope it appears as a tightly coiled tube deep in the dermis with a corkscrew-like tubule that rises through the epidermis to the surface of the skin.

The second type is the sebaceous or oil gland, which is usually located in or near a hair follicle. Sebaceous glands are located in all parts of the skin except on the palms and soles. They are particularly numerous on the face and scalp.

Sweat Glands

Sweat glands excrete a fluid known as sweat, or perspiration. The working or secreting parts of the glands are intricately coiled tubules in the dermis. There are two kinds of sweat glands, which produce different kinds of sweat.

APOCRINE

One kind, called apocrine sweat, is not very important physiologically but has some social significance. Apocrine sweat glands open into hair follicles and are limited to a few regions of the body, particularly the underarm and genital areas. Apocrine sweat is sterile when excreted but decomposes when contaminated by bacteria from the skin surface, resulting in a strong and characteristic odor. The purpose of the many cosmetic underarm preparations is to remove these bacteria or block gland excretion.

ECCRINE

The other kind of sweat, called eccrine, is of great importance to our comfort and, in some cases, our lives. Multitudes of eccrine sweat glands are present everywhere in the skin except the lips and a few other areas. They are crowded in largest numbers into skin of the palms, soles, and forehead.

Eccrine sweat is little more than extremely dilute salt water. Its function is to help the body to dissipate excessive internal heat by evaporation from the surface of the skin.

Sebaceous Glands

There are many sebaceous (oil-secreting) glands in the skin. They are distributed over almost the entire body, and are most common in regions of the forehead, face, neck, and chest—the areas typically involved in common acne, a condition associated with cell-clogged sebaceous glands. The primary function of this oily substance, or sebum, is lubrication of the hair shaft and the horny surface layers of the skin. A certain amount of natural skin oil is necessary to keep skin and hair soft and pliable.

A strap of internal, plain, involuntary muscle tissue, the arrectores pilorum ("raiser of hair"), is located in the lower portion of the hair follicle below the sebaceous glands and originates in the connective tissue of the upper dermis. Goose bumps appear on the skin when these muscles attempt to produce heat.

Blood Vessels

The skin is richly supplied with small blood vessels. The blood supply in the skin accounts for the reddening of sunburn and the coloration of the fingers beneath the nails. Engorgement of the blood vessels accounts for the reddening of the skin when we blush.

Vascular birthmarks, such as hemangiomas, strawberry marks, and port wine stains, derive their coloration from unusually large numbers of tiny blood vessels concentrated in a small area of the skin.

Hair

Hair and nails are modified forms of skin cells containing keratin as their major structural material. Keratin is produced by the same processes that change living epidermal cells into dead, horny cells. However, hair and nails are made up almost entirely of keratin.

With the exception of the palms and soles, hair follicles populate the entire cutaneous surface, although in many areas they are so inconspicuous or vestigial that they are never noticed. Hair ranges in texture from the soft, almost invisible hair on the forehead to the long hair of the scalp and the short, stiff hair of the eyelashes.

Hair follicles develop as downgrowths of the epidermis. The hair then grows outward from the bottom of the follicle. Each hair has a root, which is anchored at the bottom of the follicle, and a shaft, which extends past the top of the follicle. The hair follicle enters the epidermis and passes deep into the dermis at an angle. The follicles of long hairs can extend into the subcutaneous layer. Sebaceous glands empty into the follicle. At the root of the hair is a cone-shaped papilla that is similar to the peg-like papillae that underlie the ridges of the fingers, palms, and soles.

The hair shaft is covered with tiny, overlapping scales. An inner layer of cells contains pigment that gives the hair its color. Most hair tips project from the skin at a slant. Minute arrectores pilorum muscles attached to the follicle have the fascinating ability to make the hair stand on end, as in goose bumps.

Hair follicles and the sweat glands also serve as routes for percutaneous absorption of chemicals. Physicians sometimes use this absorptive ability of the skin in administering certain drugs, such as nitroglycerine, scopolamine, estrogen, and nicotine. Some chemicals placed on the skin can be detected in the saliva a few minutes later. In the workplace the skin is a potential route of entry for a number of hazardous chemicals.

Nails

The fingernails and toenails, like hair, are specialized forms of the skin. The fully developed nail overlays a modified part of the dermis called the nail bed.

Nails are essentially the same in structure as hair. Like hair, nails also contain keratin, but nails are flat, hard plates. The living part of a nail lies in the matrix in back of the half-moon, or lunula. If the dead nail plate, which constitutes most of the visible part of the nail, is destroyed by injury, a new nail will grow if the matrix is intact.

The growth rate of nails varies and depends on such factors as the person's age and health. Nails grow faster in young people and grow slower with serious illnesses.

PHYSIOLOGY AND FUNCTIONS

The skin performs a number of important functions. It protects the body from invasion of bacteria, injury to vital internal organs, the rays of the sun, and the loss of moisture.

Temperature Regulation

For a discussion of the role of the skin heat regulation of the body, see Chapter 12, Thermal Stress.

Sweat

Sweat is produced constantly, usually in proportion to the temperature of the environment. In hot environments, the body must lose heat by evaporation, which is more effective than simple radiation. In cool, dry weather the amount of sweat produced is relatively small and the skin remains dry to the touch. We are not aware of sweating, so the small amount of sweat produced is called insensible perspiration.

When heat production of the body is increased or when the ambient temperature is unusually high, the sweat glands produce more perspiration. The rate of production outstrips

the rate of evaporation, particularly if humidity is high, because the rate of evaporation declines with the rise in humidity. Perspiration then collects on the body in visible drops and we are conscious of sweating.

However, heat is lost only when the sweat evaporates. All sweat glands are innervated by fibers of the sympathetic nervous system, ultimately controlled by the hypothalamus. Emotional stimulation from anxiety or fright may stimulate sweating in the palms and soles.

One way of increasing the rate at which water is evaporated from the body is to breathe rapidly, thus moving larger quantities of air from the moist surfaces of the mouth, throat, and lungs. Humans cannot do this in comfort, but it is the chief method of cooling available to dogs; in warm weather, dogs sit with mouth open, tongue extended, and pant.

Ultraviolet Light

Skin protects not only against mechanical shocks, but also against various forms of ultraviolet (UV) light. (See Chapter 11, Nonionizing Radiation, for a discussion of the forms.) Most animals are protected from sunlight by scales, hair, and feathers, which absorb the sun's rays without harm to themselves.

Humans have only the skin as protection from the sun's UV rays. Ultraviolet light energy produces chemical changes within the skin's cells; the effects vary with the time of the year, the geographic area, and the hour of the day.

Generally, after initial exposure to summer sun at midday, skin shows reddening or erythema, which may not appear for several hours. If the dose of sunlight is intense, the erythema may be followed by blistering and peeling of the outer layer of epidermal cells.

If the erythema is not severe, it fades in a few days and the skin gradually acquires a tan coloration (suntan). The tan color is produced by darkening of existing pigment (immediate pigment darkening) and by increase in pigment formation. When skin is exposed to the sun, it is believed that melanin pigment moves toward the surface of the skin and is replaced by new melanin in the lower cell layer. Along with pigmentation increase, the stratum corneum thickens to furnish additional protection against solar radiation injury. One or two weeks may be required to develop a suntan by moderate daily doses of sunlight; the tan fades if occasional exposure to sunlight is not continued.

As some protection against repeated UV light exposure, human skin is equipped with the capacity to form pigment (melanin), which absorbs UV light and thus acts as a protective umbrella over the regions beneath (delayed pigment darkening).

Solar UV radiation can induce actinic (solar) degeneration and skin cancer and is a major hazard of chronic sun exposure. Chronic exposure to artificial UV light in tanning salons may induce similar changes. Additionally, sunlight and artificial UV light may induce a number of abnormal cutaneous reactions in patients with certain hereditary or acquired diseases or in those taking certain medication. Photoaging and natural chronologic aging are different entities.

There is evidence now that the immune system of humans is affected by UV radiation and that environmental sources of radiation can have similar effects, such as contact photoallergy.

One beneficial normal effect of UV radiation on skin is the photochemistry that leads to the production of vitamin D_3. In most industrial countries, sufficient vitamin D is added to food to meet normal daily requirements.

Skin Absorption

A waxy type of mixture composed of sebum, breakdown products of keratin, and sweat, called the surface lipid film, coats the outer surface of the keratin layer, but there is no evidence that this normal coating has any barrier function.

The epidermis, especially the stratum corneum, acts as the major permeability barrier to the entry of foreign chemicals into the body. Overall, the skin is selectively permeable—more impermeable than permeable—and shows regional variation in absorptive capacity. Absorption of materials through the skin markedly increases when the continuity of the skin is disrupted by dermatitis, lacerations, or punctures. The hair follicles and sweat ducts may play only a minor role in skin absorption. However, they act as diffusion shunts—that is, relatively easy pathways through the skin for certain substances such as polar compounds, very large molecules that move across the stratum corneum very slowly, and pharmacologically active substances, especially in very hairy areas. After this initial phase, however, most of the percutaneous absorption of all substances takes place across the stratum corneum, which has a much greater surface area than that of the hair follicles and sweat ducts. Absorption of fat-soluble chemicals and oils can also occur via the hair follicle.

DEFENSE MECHANISMS

Anyone who works is a candidate for occupational skin disease, yet most workers are not affected by such disorders because the skin is a primary organ of defense. The skin is able to perform its many defense functions because of its location, structure, and physiological activity.

These are the specific defenses the skin has in terms of its protection against typical industrial hazards.

- ➢ *Bacteria:* The skin is a naturally dry terrain (except in places such as armpits and the groin, and during abnormal sweating) and has a normal contingent of bacteria that tends to destroy pathogenic bacteria. Free fatty acids in the surface oil also can have some antibacterial value. The immune defenses of the skin also defend against infections.
- ➢ *Sunlight:* The skin has two defenses: an increase in pigmentation, and thickening of the stratum corneum.
- ➢ *Primary irritants:* The skin resists acids but offers much less protection against organic and inorganic alkalis.

Sweat can act as a diluent to decrease the effect of water-soluble toxins. Conversely, it enhances hydration and maceration of the barrier, thereby promoting percutaneous absorption.

- ➢ *Injury:* The skin's resilience, especially of the dermis, provides a measure of resistance to forceful impact. The cutaneous nerves also provide information about the state of the external environment through sensations of touch and temperature.
- ➢ *Excessive increase or decrease in body heat:* The body's thermoregulatory mechanisms include the activity of sweat glands and blood vessels.
- ➢ *The absorption of chemicals through the skin:* This is where the most important function is performed. The skin is a flexible body envelope and the epidermal barrier, especially the stratum corneum, provides a significant blockade against water loss from the body and penetration of the skin by chemical agents.

DEFINITIONS AND INCIDENCE OF OCCUPATIONAL SKIN DISORDERS

A dermatosis is any abnormal condition of the skin, ranging from the mildest redness, itching, or scaling to an eczematous (superficial inflammation), ulcerative (ulcer-forming), acneiform (resembling acne), pigmentary (abnormal skin color), granulomatous (tumor-like mass, nodule), or neoplastic (new, abnormal tissue growth) disorder. Occupational dermatoses include any skin abnormalities resulting directly from or aggravated by the work environment. *Dermatitis* is a more limited term referring to any inflammation of the skin, such as contact dermatitis or cement dermatitis.

Occupational skin diseases can occur in workers of all ages and in any work setting, and cause a great deal of illness, personal misery, and reduced productivity. Although the frequency of occupational skin disease often parallels the level of hygiene practiced by employers, occupational skin diseases are largely preventable. Many consider this type of disease trivial and insignificant, but occupational skin disorders can result in complex impairment. Data compiled by the U.S. Bureau of Labor Statistics (BLS) for 1991 indicate that approximately 94 percent (5,977,400) of all occupational disorders are injuries and almost 6 percent (368,300) are diseases. Because large surface areas of skin are often directly exposed to the environment, the skin is particularly vulnerable to occupational insults. Although complete data on the extent and cost of dermatological injuries are not available, the National Institute for Occupational Safety and Health (NIOSH) estimated in 1986 that skin injuries may account for 23–35 percent of all injuries. An estimated 1–1.65 million dermatological injuries may occur annually, with an estimated annual rate of skin injury of 1.4–2.2 per 100 full-time workers. The highest percentage is due to lacerations and punctures (82 percent) followed by burns (chemical and other, 14 percent) (Table 3–A).

Table 3–A. ***Occupational Dermatological Injuries in the United States, 1983***

Type of Injury	*No.*	*(%)*
Lacerations and punctures	253,141	(82.3)
Burns (nonchemical)	36,477	(11.9)
Abrasions	10,576	(3.4)
Burns (chemical)	6,828	(2.2)
Cold injuries	566	(0.2)
Radiation injuries	135	(0.04)
Total	307,723	(100.0)

(Reported by the Supplementary Data System of the Bureau of Labor Statistics from 29 participating states.)

In the mid-1950s, skin disorders other than injuries accounted for 50–70 percent of all occupational diseases. This figure has been gradually decreasing and was 13 percent, or 57,900 cases, in 1997. NIOSH attributes the decline of skin diseases since then to a continuing trend toward automation, enclosure of industrial process, and educational efforts. Despite these figures, dermatitis is the second most common cause of reported occupational disease in the United States. National data indicate that as many as 20–25 percent of all occupational skin diseases involve lost time from work, with an average of 11 workdays lost per case. California and South Carolina have reported similar data based on workers' compensation claims. The results of two studies show a serious underreporting of occupational disease of all types, which may mean that the true incidence is 10 to 50 times greater than that reported by the BLS.

NIOSH has included work-related dermatological conditions on its list of 10 leading work-related diseases and injuries in the United States (Table 3–B). Reasons include the fact that 10–15 percent of requests NIOSH receives for health hazard evaluation involve skin complaints and the fact that the economic impact of dermatological conditions is substantial. The annual cost resulting from lost worker productivity, medical care, and disability payments has been estimated to range between $222 million and $1 billion.

Table 3–C gives incidence of occupational dermatoses (disease) by industry group for the United States in 1997. The highest incidence was in agriculture (226 cases per 100,000 full-time workers). The most hazardous industrial processes for skin disorders are as follows:

- ➢ Use of cutting oils and coolants in machine tool operation
- ➢ Plastics manufacturing
- ➢ Rubber manufacturing
- ➢ Food processing
- ➢ Leather tanning and finishing
- ➢ Agriculture
- ➢ Metal plating and cleaning
- ➢ Construction
- ➢ Printing
- ➢ Forest products manufacturing

Table 3–B. *The 10 Leading Work-Related Diseases and Injuries in the United States, 1982*

Occupational lung diseases: asbestos, byssinosis, silicosis, coal worker's pneumoconiosis, lung cancer, occupational asthma	**Disorders of reproduction:** infertility, spontaneous abortion, teratogenesis
Musculoskeletal injuries: disorders of the back, trunk, upper extremity, neck, lower extremity, traumatically induced Raynaud's phenomenon	**Neurotoxic disorders:** peripheral neuropathy, toxic encephalitis, psychoses, extreme personality changes (exposure-related)
Occupational cancers (other than lung): leukemia, mesothelioma, cancers of the bladder, nose, and liver	**Noise-induced loss of hearing**
Severe occupational traumatic injuries: amputations, fractures, eye loss, lacerations, and traumatic deaths	**Dermatological conditions:** dermatoses, burns (scalding), chemical burns, contusions (abrasions)
Cardiovascular diseases: hypertension, coronary artery disease, acute myocardial infarction	**Psychological disorders:** neuroses, personality disorders, alcoholism, drug dependency

The conditions listed under each category are to be viewed as selected examples, not comprehensive definitions of the category, and are *not* in order of incidence or importance.

NIOSH developed a suggested list of the 10 leading work-related diseases and injuries. Three criteria were used to develop the list: (1) the frequency of occurrence of the disease or injury; (2) its severity in the individual case; and (3) its amenability to prevention.

Table 3–C. *Numbers and Incidence of Occupational Skin Diseases by Major Industry, 1997*

Industry	*No. of Cases*	*Incidence**
Agriculture/forestry/fishing	3,000	226
Manufacturing	26,000	139
Services	15,600	61
Transportation/utilities	3,200	52
Mining	300	51
Construction	1,800	35
Wholesale/retail trade	7,600	34
Finance/insurance/real estate	500	7
Total	57,900	67

Source: Bureau of Labor Statistics (BLS): Occupational Injuries and Illnesses in the United States 1997. U.S. Department of Labor, BLS Bulletin 2518, October 1999.

* Per 100,000 full-time workers per year.

DIRECT CAUSES OF OCCUPATIONAL SKIN DISEASE

There are unlimited substances and conditions capable of inducing a skin disorder in the workplace. Each year, new causes are reported and most can be classified under one of the following five broad headings:

- ➢ Chemical
- ➢ Mechanical
- ➢ Physical
- ➢ Biological
- ➢ Botanical

Chemical

Organic and inorganic chemicals are the predominant causes of dermatoses in the work environment (Table 3–D). The list of such chemicals is endless because each year additional agents capable of injuring the skin are added. Chemical agents may be divided into two groups: primary irritants and sensitizers.

PRIMARY IRRITANTS

These are likely to affect most people; some actually affect everyone. These agents react on contact. The reaction alters the chemistry of the skin by dissolving a portion of it by precipitating the protein of the cells, or by some other chemical reaction. The result can range from tissue destruction (chemical burn) to inflammation (dermatitis) depending on the strength of the agent and the duration of the exposure.

Primary irritants damage skin because they have an innate chemical capacity to do so. Many irritants are water-soluble and thus react with certain components of the skin. The water-insoluble compounds, including many solvents, react with the lipid (fatty) elements within skin. The precise mechanism of primary irritation on the skin is not known, but some useful generalizations explain the activity of groups of materials in the irritant category. About 80 percent of all occupational dermatoses are caused by primary irritants. Dermatitis caused by a primary irritant is referred to as irritant contact dermatitis because the skin irritation is normally confined to the area of direct contact.

Most inorganic and organic acids act as primary irritants. Certain inorganic alkalis, such as ammonium hydroxide, calcium chloride, sodium carbonate, and sodium hydroxide, are skin irritants. Organic alkalis, particularly amines, also are active irritants. Metallic salts, especially arsenicals, chromates, mercurials, nickel sulphate, and zinc chloride, severely irritate the skin. Organic solvents include many substances, such as chlorinated hydrocarbons, petroleum-based compounds, ketones, alcohols, and terpenes, that irritate the skin because of their solvent qualities (Figure 3–2).

Keratin solvents. All of the alkalis, organic and inorganic, injure the keratin layer with sufficient concentration and exposure time. These agents soften, dehydrate, and destroy the keratin cells, resulting in dry, cracked skin. This prepares the way for secondary infection and, at times, for the development of allergic contact dermatitis.

Keratin stimulants. Several chemicals stimulate the skin so that it undertakes growth patterns that can lead to tumor or cancer formation. Certain petroleum products, a number of coal tar-based materials, arsenic, and some polycyclic aromatic hydrocarbons can stimulate the epidermal cells to produce these effects (Figure 3–3).

Table 3–D. *Selected Chemical Causes of Skin Disorders*

Chemical	Primary Irritants	Sensitizers	Selected Skin Manifestations (some also have important systemic effects on other organs)	Selected Occupations, Trades, or Processes Where Exposure Can Occur
ACIDS				
Acetic	X	?	Dermatitis and ulceration	Manufacturing acetate rayon, textile printing and dyeing, vinyl plastic makers
Carbolic (phenol)	X		Corrosive action on skin, local anesthetic effect	Carbolic acid makers, disinfectant manufacturing, dye makers, pharmaceutical workers, plastic manufacturing
Chromic	X	X	Ulcers ("chrome holes") on skin, inflammation and perforation of nasal septum	Platers, manufacturing organic chemicals and dyestuffs
Cresylic	X		Corrosive to skin, local anesthetic effect	Manufacturing disinfectants, coal tar pitch workers, foundry workers
Formic	X		Severe irritation with blisters and ulcerations	Rubber and laundry workers, mordanters, cellulose formate workers, airplane dope makers
Hydrochloric	X		Irritation and ulceration of skin	Bleachers, picklers (metals), refiners (metals), tinners, chemical manufacturing, masons (clean cement)
Hydrofluoric	X		Severe chemical burn with blisters, erosion, or ulceration	Enamel manufacturing, etchers, hydrofluoric acid makers, fluorochemical workers
Lactic	X		Ulceration (if strong solutions are used)	Adhesives, plastics, textiles
Nitric	X		Severe skin burns and ulcers	Nitric acid workers, electroplaters, old metal cleaners, acid dippers, nitrators, dye makers
Oxalic	X		Severe corrosive action on skin, cyanosis (bluish discoloration), and brittleness of nails	Tannery workers, blueprint paper makers, oxalic acid makers
Picric	X	X	Erythema, dermatitis, scaling, yellow discoloration of skin and hair	Explosives workers, picric acid makers, dyers and dye makers, tannery workers
Sulfuric	X		Corrosive action on skin, severe inflammation of mucous membranes	Nitrators, picklers (metals), dippers, chemical manufacturing
ALKALIS				
Ammonia	X		Irritation including airborne dermatitis of face from vapors	Ammonia production, fertilizers, photocopying (blueprint, diazo); gas and liquid forms
Calcium cyanamide	X		Irritation and ulceration	Fertilizer makers, agricultural workers, nitrogen compound makers
Calcium oxide	X		Dermatitis, burns, or ulceration	Lime workers, manufacturing of calcium, salts, glass, and fertilizer
Potassium hydroxide	X		Severe corrosion of skin, deep-seated persistent ulcers, loss of fingernails	Potassium hydroxide makers, electroplaters, paper, soap, and printing ink makers
Sodium hydroxide	X		Severe corrosion of skin, deep-seated persistent ulcers, loss of fingernails	Sodium hydroxide makers, bleachers, soap and dye makers, petroleum refiners, mercerizers, plastic manufacturing
Sodium or potassium cyanide	X		Blisters, ulcers	Electroplaters, case hardening, extraction of gold
Trisodium phosphate	X		Blisters, ulcers	Photographic developers, leather tanning, industrial cleaning detergents
SALTS OR ELEMENTS				
Antimony and its compounds	X	?	Irritation and lichenoid eruptions of skin	Antimony extractors, glass and rubber mixers, manufacturing of various alloys, fireworks, and aniline colors

(Continues)

Table 3–D. *Selected Chemical Causes of Skin Disorders (Continued)*

Chemical	Primary Irritants	Sensitizers	Selected Skin Manifestations (some also have important systemic effects on other organs)	Selected Occupations, Trades, or Processes Where Exposure Can Occur
SALTS OR ELEMENTS (continued)				
Arsenic and its compounds	X	X	Spotty pigmentation of skin, perforation of nasal septum, skin cancer, keratoses especially on palms and soles, dermatitis, pustules	Leather workers, manufacturing insecticides, glass industry, agriculture, pesticides, tanning, taxidermy, alloy, lubricating oils
Barium and its compounds	X		Irritation of skin	Barium carbonate, fireworks, textile dyes, and paint makers
Bromine and its compounds	X		Irritation, vesicles, and ulceration; acne	Bromine extractors, bromine salts makers, dye and drug makers, photographic trades
Chromium and its compounds	X	X	Pitlike ulcers (chrome holes) on skin, perforation of nasal septum, dermatitis	Chromium platers, dye industry workers, chrome manufacturing, leather tanners
Mercury and its compounds	X	X	Corrosion and irritation of skin, dermatitis	Explosives manufacturing, silver and gold extractors, manufacturing electrical appliances and scientific equipment
Nickel salts	X	X	Folliculitis, dermatitis	Nickel platers, alloy makers
Sodium and certain of its compounds	X		Burns and ulceration	Bleaching: detergent, paper, glass, tetraethyl lead manufacturing
Zinc chloride	X	?	Ulcers of skin and nasal septum	Manufacturing chemicals, dyestuffs, paper, disinfectants
SOLVENTS				
Acetone	X		Dry (defatted) skin	Spray painters, celluloid industry, artificial silk and leather workers, acetylene workers, lacquer and varnish makers, garage mechanics
Benzene and its homologues (toluene and xylene)	X		Dry (defatted) skin	Chemical and rubber manufacturing
Carbon disulfide	X	X	Dry (defatted) irritated skin	Extraction of oils, fats, and a wide range of other materials, manufacture of rayon, rubber, rubber cements, germicides, and other chemicals
Trichloroethylene	X	?	Dermatitis	Degreasers, chemical intermediates
Turpentine	X	X	Dermatitis	Painters, furniture polishers, lacquerers, artists
Alcohols (such as ethanol)	X	X	Dermatitis	Chemical manufacture; painters
SOME DYE INTERMEDIATES				
Dinitrobenzene	X		Yellow discoloration of skin, hair, and eyes	Dye manufacturing
Nitro and nitroso compounds	X	X	Dermatitis	Dye manufacturing
Phenylhydrazine	X	X	Severe chemical burns, dermatitis	Dye and pharmaceutical manufacturing
PETROLEUM AND COAL-TAR DERIVATIVES				
Petroleum oils	X		Dermatitis, folliculitis	Petroleum workers, machinists, mechanics
Pitch and asphalt	X		Dermatitis, folliculitis, keratoses, skin cancer	Manufacturing pitch and asphalt, roofers
Tar (coal)	X	X	Dermatitis, folliculitis, skin cancer, eye inflammation (keratitis)	Tar manufacturing, manufacturing roofing paper and pitch, road building and repairing
DYES (such as paraphenylenediamine)	X		Contact dermatitis (erythema, blisters, edema)	Dye workers, cosmetologists

(Continues)

Table 3–D. *Selected Chemical Causes of Skin Disorders (Continued)*

Chemical	Primary Irritants	Sensitizers	Selected Skin Manifestations (some also have important systemic effects on other organs)	Selected Occupations, Trades, or Processes Where Exposure Can Occur
RUBBER ACCELERATORS AND ANTIOXIDANTS	X		Contact dermatitis (erythema, blisters, edema)	Rubber workers, such as compound mixers and calendar and mill operators; fabricators of rubber products
Mercaptobenzothiazole, tetramethylthiuram disulfide, diethylthiourea, and paraphenylenediamine				
SOAPS AND SOAP POWDERS	X	X	Dermatitis, dry skin, paronychia (inflammation around fingernails); allergy from fragrance, germicides, or dyes	Soap manufacturing, dishwashers, soda fountain clerks, maintenance workers—all associated with wet work
INSECTICIDES				
Arsenic	X		See above under salts or elements	Manufacturing and applying insecticides
Pentachlorophenols	X	?	Dermatitis, chloracne	Pesticides and wood preservatives
Creosote	X	X	Dermatitis, folliculitis, keratoses, hyperpigmentation, skin cancer	Manufacturing wood preservatives, railroad ties, coal tar lamp black and pitch workers
Fluorides	X		Severe burns, dermatitis	Manufacturing insecticides, enamel manufacturing
Phenylmercury compounds	X	X	Dermatitis	Manufacturing and applying fungicides and disinfectants
Pyrethrum		X	Dermatitis	Manufacturing and applying insecticides
Rotenone	X		Dermatitis	Manufacturing and applying insecticides
RESINS (Natural)*				
Cashew nut oils		X	Severe poison ivylike dermatitis	Handlers of unprocessed cashew nuts, varnish
Rosin		X	Dermatitis	Adhesive and paper mill workers, dentists, rubber industry
Shellac		X	Dermatitis	Coatings, cosmetics
Synthetic resins such as phenolformaldehyde, urea-formaldehyde, epoxy, vinyl, polyurethane, polyester, acrylate, cellulose esters	X	X	Dermatitis	Plastic workers, varnish makers, adhesives, coatings, rubber, cosmetology
* The skin reactions from this group of chemicals in some instances are due to the essential composition of the synthetic resin, but in other cases are due to the presence of added compounds such as plasticizers and other modifying agents.				
EXPLOSIVES				
Nitrates, mercury fulminate, tetryl, lead azide, TNT, nitroglycerin	X	X	Severe irritation, dermatitis, skin discoloration	Explosives manufacturing, shell loading
METAL WORKING FLUIDS				
Cutting oils	X		Oil acne (folliculitis), rare dermatitis	Machinists
Coolants—synthetic and semisynthetic	X	X	Dermatitis	Machinists
OXIDIZING AGENTS				
Hydrogen peroxide	X	?	Dermatitis	Chemical industry; medical disinfectant; cosmetology
Benzoyl peroxide	X	X	Dermatitis	Chemical industry; polyester manufacture
OTHER				
Isocyanates such as TDI, MDI, HDI	X	X	Dermatitis	Polyurethane makers, adhesive workers, organic chemical synthesizers
Vinyl chloride	X		Dermatitis, acro-osteolysis	Polyvinyl resin, rubber and organic chemical makers
Formaldehyde	X	X	Dermatitis	Undertakers, biologists, textile workers
Plants, weeds (such as poison oak, ivy, sumac)	X	X	Dermatitis	Outdoor workers (such as fire fighters, utility workers)

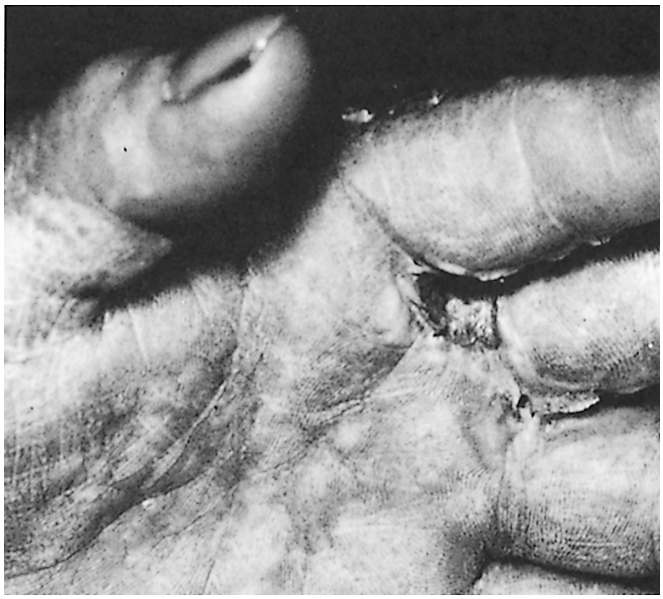

Figure 3–2. Eczematous dermatitis is a form of contact dermatitis caused by contact with organic solvents. It is one of the most prevalent types of dermatitis.

Fats and oil solvents. Just as organic solvents dissolve oily and greasy industrial soils, they remove the skin's surface lipids and disturb the keratin layer of cells so that they lose their water-holding capacity. Workers exposed each day to organic solvents develop exceedingly dry and cracked skin.

Protein precipitants. Several of the heavy metal salts precipitate protein and denature it. The salts of arsenic, chromium, mercury, and zinc are best known for this action.

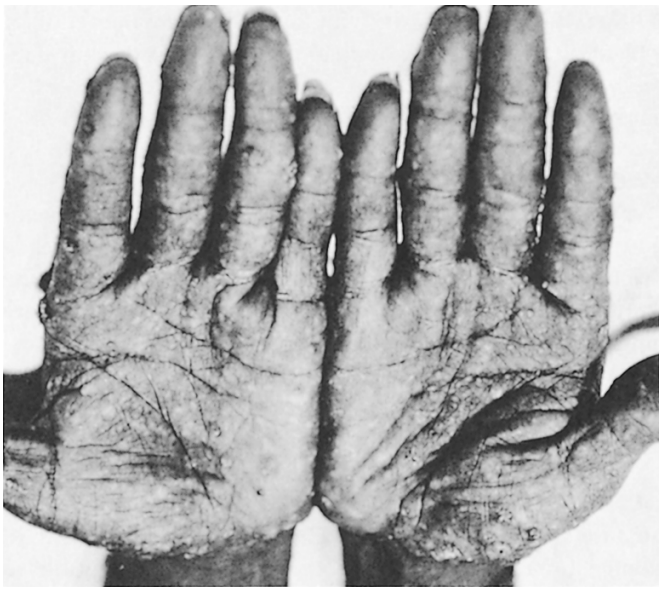

Figure 3–3. Nodules in the keratin layer of the skin may result from repeated exposure to certain tars or coal tar derivatives.

Reducers. In sufficient concentration, salicylic acid, oxalic acid, urea, and other substances can actually reduce the keratin layer so that it is no longer protective, and an occupational dermatosis results.

SENSITIZERS

Some primary skin irritants also sensitize. Certain irritants sensitize a person so that a dermatitis develops from a very low, nonirritating concentration of a compound that previously could have been handled without any problem.

Some chemical and many plant substances and biological agents are classified as sensitizers. Initial skin contact with them may not produce dermatitis, but after repeated or extended exposure some people develop an allergic reaction called allergic contact dermatitis. Clinically, allergic contact dermatitis is often indistinguishable from irritant contact dermatitis (see sections on contact dermatitis for further discussion of allergic contact dermatitis and patch testing).

Substances that are both irritants and allergens include turpentine, formaldehyde, chromic acid, and epoxy resin components. Common sensitizers are plant oleoresins such as poison ivy, epoxy resins, azo dyes, certain spices, certain metals such as nickel and chromium, and topical medicaments such as neomycin.

Other chemicals can sensitize the skin to light. Known as photosensitizers, these chemicals include coal tar and pitch derivatives, fluorescent dyes, salicylanilides, musk ambrette, sunscreens containing p-aminobenzoic acid (PABA) and benzophenone, some plants, pesticides, and insecticides.

Mechanical

Trauma at work can be mild, moderate, or severe and occur as a single or repeated event. Friction results in the formation of a blister or callus, pressure in thickening and color change, sharp objects in laceration, and external force in bruising, punctures, or tears. A commonly cited example is fibrous glass, which can cause irritation, itching, and scratching. Secondary infection may complicate blisters, calluses, or breaks in the skin.

Physical

Physical agents such as heat, cold, and radiation can cause occupational dermatoses. For example, high temperatures cause perspiration and softening of the outer horny layer of the skin. This can lead to miliaria, or heat rash, common among workers exposed to hot humid weather, electric furnaces, hot metals, and other sources of heat.

High temperatures can also cause systemic symptoms and signs such as heat cramps, heat exhaustion, and even heat stroke. Burns can result from electric shock, sources of ionizing radiation, molten metals and glass, and solvents or detergents used at elevated temperatures.

Exposure to low temperatures can cause frostbite and result in permanent damage to blood vessels. The ears, nose, fingers, and toes are the most often frostbitten. Electric utility and

telephone line workers, highway maintenance workers, agricultural workers, fishermen, police officers, letter carriers, and other outdoor workers are most often affected.

Sunlight is the greatest source of skin-damaging radiation and is a source of danger to construction workers, fishermen, agricultural workers, foresters, and all others who work outdoors for extended periods of time. The most serious effect on the skin is skin cancer.

Increasing numbers of people come into casual or prolonged contact with artificial UV light sources such as molten metals and glass, welding operations, and plasma torches. A wide variety of newer lasers are being used in medicine and other scientific disciplines. Because lasers can injure the skin, eye, and other biological tissue, it is important to use appropriate protective devices.

Ionizing radiation sources include the following:

- Alpha-radiation is completely stopped by the skin and thus does not injure skin. However, alpha-radiation-emitting radioactive substances, such as plutonium, are harmful when ingested or inhaled.
- Beta-radiation can injure the skin by contact and substances such as phosphorus-32 are dangerous when inhaled or ingested. Beta-particles are usually localized at the surface or within the outer layers of skin, with the depth of penetration depending on the energy of the beta particle.
- Gamma-radiation and x-rays are well-known skin (radiodermatitis and skin cancer) and systemic (internal) hazards when sufficient exposure occurs. Radiodermatitis is characterized by dry skin, hair loss, telangiectasia, spider-like angiomas, and hyperkeratosis. Skin cancer may ultimately develop. (See Chapter 10, Ionizing Radiation, for more information.)

Biological

Bacteria, viruses, fungi, and parasites can produce cutaneous or systemic disease of occupational origin. Animal breeders, agricultural workers, bakers, culinary employees, florists, horticulturists, laboratory technicians, and tannery workers are among those at greater risk of developing infections. Examples include anthrax in hide processors; yeast infections of the nail in dishwashers, bartenders, and others engaged in wet work; and animal ringworm in agricultural workers and veterinarians. Parasitic mites are common inhabitants of grain and other foodstuffs and attack those handling such materials, such as grocers, truckers, longshoremen, and agricultural workers. Outdoor workers such as bricklayers and plumbers in southeastern states risk contracting animal hookworm via larvae deposited by infected animals in sandy soil. Health care workers, medical laboratory workers, and emergency medical technicians are exposed to a number of microorganisms, especially hepatitis B, HIV, herpes simplex (herpetic whitlow of the fingers from direct viral exposure and inoculation), fungi (*Candida* and superficial and deep fungi), and bacteria (staphylococci and tuberculosis), which may be acquired from patients or from biological specimens.

Botanical

Many plants and woods, of which poison ivy and poison oak are the most common, can cause contact dermatitis. Irritant contact dermatitis can also be caused by some plants, and although the chemical identity of many of the toxins is not known, the allergen or irritant occurs in the leaves, stems, flowers, bark, or other part of the plant. Other plants, such as wild parsnip and fresh or diseased celery (pink-rot) are photosensitizers. Several outbreaks of photodermatitis have been reported in grocery produce workers, especially those visiting tanning parlors. With woods, dermatitis occurs especially when they are being sandpapered, polished, and cut. Fomites can carry and transmit these allergens, which can also be dispersed by the smoke from burning.

PREDISPOSING FACTORS

In classifying and determining the severity of occupational dermatoses, a number of factors should be considered: the nature, duration, and extent of exposure to an environmental agent, the potential toxic effects of the agent, its chemical stability, and its potential for being absorbed through the skin. Other variables include preexisting skin disease or exposure to more than one agent. Indirect or predisposing factors leading to the development of occupational dermatoses are generally associated with age, sex, skin type, perspiration, season of the year, personal hygiene, and allergy.

Age and Experience

Younger, inexperienced, and inadequately trained workers have a higher prevalence of occupational dermatoses than older workers. However, older workers may be prone to chronic skin irritation because their skin is generally drier.

Skin Type

Workers with naturally dry skin cannot tolerate the action of solvents and detergents as well as persons with oily skin (Figure 3–4). Hairy arms and legs are common sites of folliculitis and acne induced by cutting oils (Figure 3–5).

Sweating

Hyperhidrosis, or increased sweating, can produce maceration with softening and resultant separation of skin already irritated by rubbing in adjacent body areas, as occurs in the armpit and the groin. This predisposes the skin to secondary fungal and bacterial infection. Some materials, such as caustics, soda ash, and slaked lime, become irritants in solution. However, sweating can also serve a protective function by diluting the toxic substances.

Gender

Because the incidence of nickel allergy is much greater in women (due to ear-piercing), they are more susceptible to developing dermatitis when handling coins or when in contact with nickel salts and metal alloys. The incidence of

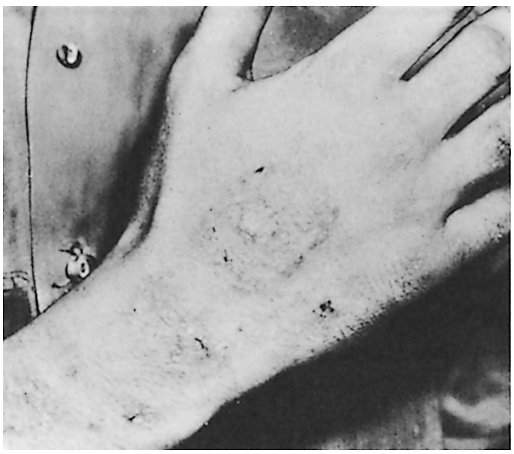

Figure 3–4. Cleaning hands with a strong petroleum solvent instead of a good industrial cleanser caused this case of dermatitis.

Figure 3–5. Acneiform disorder, shown on this worker's forearm, is often caused by exposure to cutting oils. Lack of splash guards and poor personal hygiene can be factors.

nickel allergy in men, even those with earrings, is lower, for reasons that are not known. A recent study suggested that women are more easily sensitized than men.

Seasons and Humidity

Occupational dermatoses are more common in warm weather, when workers wear less clothing and are more likely to come in contact with external irritants. Excessive perspiration, with resulting skin damage, is also more common in warm weather. When a work area is hot, workers may not use protective clothing. Warm weather also means that many workers have greater exposure to sunlight, poisonous plants, and insects, the effects of which may or may not be related to the job.

Winter brings chapping from exposure to cold and wind. Heated rooms usually are low in relative humidity, so skin loses moisture. Large-scale outbreaks of dermatitis in some factories has been traced to nothing more than low humidity. Clothing can keep dust particles and mechanical irritants in close contact with the skin. Infrequent bathing and changing of clothing can increase the incidence of skin irritation. (See Chapter 12, Thermal Stress, for more information.)

Hereditary Allergy (Atopy)

Atopy (the name means *uncommon* or *out of place*) is a relatively common genetic tendency toward the development of atopic dermatitis, asthma, and hay fever. Atopic people are predisposed to developing dermatitis because of their reduced skin resistance to chemical irritants, inherent dry skin, dysfunctional sweating, and a high skin colonization rate of the bacterium *Staphylococcus aureus.* In an atopic adult, the hands are the main location for dermatitis. Atopic people, especially those with eczema, are more prone to irritant dermatitis than those who are not atopic. Atopy is common among hairdressers, health care workers, and others performing wet work. Contact allergy and contact urticaria—especially to latex—also occur in atopic workers.

Personal Hygiene

Poor personal hygiene is believed to be a major factor causing occupational skin disorders. Unwashed skin covered with unwashed and unchanged clothes may be in prolonged contact with chemicals. Responsibility for maintaining clean skin is shared by employer and employee. Thus, adequate facilities for maintaining personal cleanliness should be provided in every place of employment. Educating workers in the preventive aspects of personal hygiene is imperative. On the other hand, excessive skin cleansing with harsh agents can produce an irritant contact dermatitis or aggravate preexisting dermatitis.

Preexisting Skin Disease

Other forms of skin irritation (eczema), such as atopic eczema, nonoccupational contact dermatitis, palmar psoriasis, and lichen planus, can be aggravated by chemicals in the work environment. Ultraviolet light-sensitive disease, such as lupus erythematosus, and cold-induced disease, such as Raynaud's phenomenon, can be aggravated and precipitated by sunlight and cold exposure, respectively.

CLASSIFICATION OF OCCUPATIONAL SKIN DISEASE

Skin disorders are relatively easy to recognize because they are visible. However, accurate diagnosis and classification of disease type and its relationship to employment usually requires a high level of clinical skill and expertise. The varied nature of skin responses causing occupational skin disorders takes several forms. The appearance and pattern of the dermatosis seldom indicates the provoking substance definitively, but can provide clues to the class of materials involved. Diagnosis depends on appearance, location, and (most importantly) on the history. Preexisting skin disorders, adverse effects of treatment, and secondary infections add to the difficulty in diagnosis. The following grouping includes most occupational dermatoses.

Contact Dermatitis

Contact dermatitis is the most frequent cause of occupational skin disease, accounting for most reported cases. Two types are generally recognized: irritant and allergic. Approximately 80 percent of all cases of occupational contact dermatitis result from irritation and 20 percent from allergy. Both are difficult to differentiate clinically because each can appear as an acute or chronic eczematous dermatitis. The acute form is erythematous (increased redness), vesicular (small blisters) to bullous (large vesicles), edematous (swollen), and oozing, and of short duration, lasting days or weeks. The chronic form is lichenified (thickened skin), scaly, and fissured, and may last for weeks, months, or years. Itching is usually a major symptom.

Contact dermatitis most often occurs on the hands, wrists, and forearms, although any area can be affected. Dusts, vapors, and mists can affect the exposed areas, including forehead, eyelids, face, ears, and neck, and often collect in areas where the body bends, such as under the collar and at the tops of shoes. The palms and soles are partially protected by a thick stratum corneum. The scalp tends to be protected by the hair, but the male genitalia are commonly affected, as irritants are often transferred by the hands. Contact dermatitis also localizes under rings and between fingers, toes, and other cutaneous areas that rub together.

IRRITANT CONTACT DERMATITIS

A primary skin irritant is a substance that causes damage at the site of contact because of its direct chemical or physical action on the skin. Irritants are generally divided into strong (absolute) and weak (marginal) types. Strong (absolute) irritants include strong acids, alkalis, aromatic amines, phosphorus, ethylene oxide, riot-control agents, and metallic salts, and produce an observable effect within minutes. In contrast, marginal irritants such as soap and water, detergents, solvents, and oils can require days before clinical changes appear. Cumulative exposure to marginal irritants causes most cases of occupational irritant dermatitis and is a major skin problem in the workplace. (See the following pages for further discussion and lists of irritants and sensitizers.)

Important factors to consider in irritant dermatitis are the nature of the substance (pH, solubility, physical state, concentration, duration of contact, and host and environmental factors). Despite the prevalence of irritant dermatitis, much is unknown about the precise mechanisms of how irritants disturb the skin. Several points merit emphasis:

- ➢ Contact dermatitis can occur from contact with several marginal irritants, the effects of which are cumulative.
- ➢ Cumulative irritant contact dermatitis can lead to skin fatigue, a condition in which even mild substances can irritate the skin, or to "hardening," in which the skin eventually accommodates repeated exposure to an offending agent.
- ➢ The clinical and histological differentiation of irritant and allergic contact dermatitis is often difficult or impossible.
- ➢ Constant exposure to irritants impairs the barrier function of the skin and allows penetration of potential allergens.
- ➢ Irritant and allergic contact dermatitis often coexist in the same patient.

ALLERGIC CONTACT DERMATITIS

A variety of industrial chemicals are potential contact allergens. The incidence of allergic contact dermatitis varies depending on the nature of the materials handled, predisposing factors, and the ability of the physician to accurately use and interpret patch tests. Allergic contact dermatitis, in contrast with primary irritation, is a form of cell-mediated, antigen–antibody immune reaction. Sensitizing agents differ from primary irritants in their mechanism of action and their effect on the skin. Unless they are concomitant irritants, most sensitizers do not produce a skin reaction on first contact. Following this sensitization phase of one week or longer, further contact with the same or a cross-reacting substance on the same or other parts of the body results in an acute dermatitis (elicitation phase).

Other essential points about allergic contact dermatitis include the following:

- ➢ As a general rule, a key difference between irritation and allergic contact dermatitis is that an irritant usually affects many workers, whereas a sensitizer generally affects few. Exceptions exist with potent sensitizers, such as poison oak oleoresin, or epoxy resin and components.
- ➢ Differentiation of marginal irritants from skin allergens also can be difficult. Marginal irritants may require repeated or prolonged exposure before a dermatitis appears; allergic contact dermatitis also may not develop for months or years after exposure to an agent.
- ➢ Many skin sensitizers, such as chromates, nickel salts, and epoxy resin hardeners, are also primary irritants.
- ➢ However, sensitization (allergy) can be produced or maintained by allergens such as nickel, chromates, formaldehyde, and turpentine in minute amounts and in concentrations insufficient to irritate the nonallergic skin.
- ➢ Cross-sensitivity is an important phenomenon in which a worker sensitized to one chemical also reacts to one or more closely related chemicals. A number of examples exist: rhus antigens such as poison oak, ivy, sumac, Japanese lacquer, mango, and cashew nutshell oil; aromatic amines such as p-phenylenediamine, procaine, benzocaine, and p-aminobenzoic acid (sunscreens); and perfume or flavoring agents such as balsam of Peru, benzoin, cinnamates, and vanilla.
- ➢ Systemic contact dermatitis is a widespread, eczematous contact-like dermatitis that can result from oral or parenteral (intravenous or intramuscular) administration of an allergen to which a worker is sensitized topically (such as oral administration of sulfonamides and thiazide diuretics in patients with contact allergy to p-phenylenediamine and benzocaine-containing topical anesthetics).

➢ Patch testing is used to differentiate allergic contact dermatitis from irritant dermatitis. The sine qua non for the diagnosis of allergic contact dermatitis is a properly performed and interpreted positive patch test.

The most common contact sensitizers in the general population have been determined from clinical experience and from published studies on the prevalence of positive patch test reactions in dermatology departments. Major sensitizers include the following:

➢ Rhus (poison oak, ivy, and sumac)
➢ P-phenylenediamine
➢ Nickel
➢ Rubber chemicals
➢ Quaternium-15 (a formaldehyde-releasing preservative)
➢ Topical medicaments containing benzocaine, antihistamines such as diphenhydramine, and antibiotics such as neomycin and bacitracin

Additional industrial allergens include the following:

➢ Chromates
➢ Plastics and adhesives (especially epoxy and acrylic resins)
➢ Formaldehyde and other preservatives
➢ Mercury
➢ Cobalt

Contact Urticaria/Latex Allergy

Contact urticaria is characterized by the appearance of urticaria, or hives, usually within several minutes at the site of contact with a wide variety of substances. There are three types: immunologic, nonimmunologic, and contact urticaria of uncertain mechanism. The nonimmunologic type is most common; causes include substances that release histamine or other vasoactive substances, such as plants (nettles), insects (caterpillars and moths), cobalt chloride, cinnamic aldehyde, nicotinic acid esters (trafuril), and dimethyl sulfoxide. Causes of contact urticaria of uncertain type include ammonium persulfate, certain types of solar urticaria (caused by sun exposure) and aquagenic urticaria (caused by water exposure). Examples of agents that may produce immunologic contact urticaria include penicillin, nitrogen mustard, neomycin, and the insect repellant diethyl toluamide (DEET).

The paradigm for the immunologic type of contact urticaria is natural rubber latex (NRL) allergy, which has become a significant medical and occupational health problem. Most affected patients have contact urticaria, but others have experienced generalized urticaria, angioedema, asthma, and anaphylaxis including vascular collapse and death. Terminology established by the Latex Task Force of the Health Industry Manufacturers Association identified natural latex as the milky fluid of agriculture origin produced by the *Hevea brasiliensis* tree. NRL refers to products made directly from water-based, natural latex emulsions. Gloves, balloons, tourniquets, and condoms are examples of products produced by means of dipping porcelain forms into liquid latex. Dry rubber latex refers to products made from processed, dried, or milled sheets of latex rubber. Syringe plungers, vial stoppers, and baby-bottle nipples are examples of extruded or compression-molded dry products. Most immediate-type reactions result from exposure to NRL products that are dipped. Dry-molded rubber products contain lower residual latex protein levels or have less easily extracted proteins than do dipped products produced from NRL. This may explain the relative lack of reports of NRL allergy in the tire industry.

Latex allergy is an immunoglobulin (Ig) E-mediated hypersensitivity to one or more of a number of proteins present in raw or cured NRL. Individuals at highest risk are patients with spina bifida (30–65 percent prevalence), health care workers, and other workers with significant NRL exposure. Most reported series of occupational cases involve health care workers, affecting 5–11 percent of those studied. Studies of populations of nonhealth care workers are infrequent and include kitchen workers, cleaners, rubber band, surgical glove, latex doll-manufacturing workers, and miscellaneous other occupations. Predisposing risk factors are hand eczema, allergic rhinitis, allergic conjunctivitis, or asthma in individuals who frequently wear NRL gloves; mucosal exposure to NRL; and multiple surgical procedures.

The spectrum of clinical signs ranges from contact urticaria, generalized urticaria, allergic rhinitis, allergic conjunctivitis, angioedema, and asthma to anaphylaxis. The majority of cases involve reactions to NRL gloves, i.e., donning NRL gloves or being examined by individuals wearing NRL gloves. Reactions from other medical and nonmedical NRL devices have occurred; these include balloons, rubber bands, condoms, vibrators, dental dams, anesthesia equipment, and toys for animals and children. The route of exposure to NRL proteins is important, and it includes direct contact with intact or inflamed skin and mucosal exposure, such as inhalation of powder from NRL gloves, especially in medical facilities and in operating rooms.

NRL allergy is sometimes associated with allergic reactions to fruit, especially bananas, kiwi, chestnuts, and avocados. This results from cross-reactivity between proteins in NRL and those found in the fruits. Symptoms range from oral itching and angioedema to asthma, gastrointestinal upset, and anaphylaxis.

Diagnosis of NRL allergy is strongly suggested by obtaining a history of angioedema of the lips when inflating balloons, and/or itching, burning, urticaria, or anaphylaxis when donning gloves, when undergoing surgical, medical, and dental procedures, or following exposure to condoms or other NRL devices. Diagnosis is confirmed by either a positive wear-or-use test with NRL gloves, a valid positive intracutaneous prick test to NRL, or a positive serum RAST to NRL. Severe allergic reactions have occurred from prick-and-wear tests; epinephrine and resuscitation equipment free of NRL should be available during these procedures.

Hyposensitization to NRL is not yet possible, and NRL avoidance and substitution are imperative. Because many patients with NRL allergy are atopic with hand eczema, immediate allergic symptoms, or both, the most important

issues for physicians are accurate diagnosis, appropriate treatment, and counseling. Dermatologic evaluation to exclude other causes of hand eruptions and allergy or pulmonary evaluation of associated rhinitis, conjunctivitis, asthma, angioedema or anaphylaxis is important.

Prevention and control of NRL allergy includes latex avoidance in health-care settings for affected workers and patients. Substitute synthetic non-NRL gloves and other personal protective equipment such as surgical masks and disposable respirators should be available; and in many cases, low-allergen NRL gloves should be worn by coworkers to accommodate those with NRL allergy, in order to minimize symptoms and to decrease induction of NRL allergy. Synthetic non-NRL gloves include those made of poly(vinyl chloride) (vinyl), block polymers (styrene-butadiene-styrene and styrene-ethylene-butylene-styrene), chloroprene (Neoprene®), polyurethane, synthetic polyisoprene, and nitrile.

Allergen content of gloves should be requested from manufacturers and suppliers; lists of glove allergen levels have also been published (see Bibliography, Palosuo et al, 1998). Patients with NRL allergy should obtain MedicAlert bracelets and inform health care providers of their diagnosis, and be given lists of substitute gloves, other non-NRL devices, potentially allergenic fruits, a latex-safe anesthesia protocol, and occult sources of NRL exposure such as dog and child toys, and dental prophylaxis cups. Some of this information is available in published sources and from latex allergy support groups. One group is ELASTIC (Education for Latex Allergy Support Team and Information Coalition), which provides Latex Allergy News (800/482-6869). Another is ALERT (Allergy to Latex Education and Support Service) (414/677-9707). The National Institute for Occupational Safety and Health (NIOSH) has issued a review on preventing allergic reactions to NRL in the workplace (NIOSH Alert, 1997).

Other information on latex allergy is available from the Spina Bifida Association of America (202/944-3285). The FDA recently issued a rule requiring labeling of NRL devices and outlining substitute language to replace the "hypoallergenic" label. The old "hypoallergenic" label was designed to prevent Type IV allergic contact dermatitis rather than Type I NRL allergy. Since these "hypoallergenic" gloves were still made of NRL, they caused adverse reactions in some patients with NRL allergy. (See the section on Gloves, later in this chapter.)

Photosensitivity

Photosensitivity is the capacity of an organ or organism or certain chemicals and plants to be stimulated to activity by light or to react to light. Two types are generally recognized: phototoxicity and photoallergy. Phototoxicity, like primary irritation, can affect anyone, although darkly pigmented people are more resistant. Photoallergens, like contact allergens, involve immune mechanisms and affect fewer people.

Industrial sources of photosensitivity can be obscure, requiring careful epidemiological and clinical investigation including photopatch testing. An example is phototoxicity from p-aminobenzoic acid used in the manufacture of ultraviolet-cured inks. Medical personnel may be occupationally exposed to photosensitizing drugs. Other workers who can have contact with topical photosensitizers include outdoor and field workers (photosensitizers in plants and chemicals), machinists (antimicrobials in metalworking fluids), pharmaceutical workers (drugs, dyes, and fragrances), and oil field, road construction, and coal tar workers (tars, pitch, and other hydrocarbons).

Occupational Acne

Occupational acne results from contact with petroleum and its derivatives, coal tar products, or certain halogenated aromatic hydrocarbons (Table 3–E). The eruption can be mild, involving localized, exposed, or covered areas of the body, or severe and generalized, with acne involving almost every follicular orifice. Chloracne, in addition to being a difficult cosmetic and therapeutic problem, is of considerable concern because it is caused by highly toxic chemicals.

Occupational acne is seen most commonly in workers exposed to cutting oils in the machine tool trades. The insoluble (straight) oils are the most common cause (see Figure 3–5). Oil acne typically starts as comedones and an inflammatory folliculitis affecting the tops of the hands and extensor surfaces of the forearms. However, covered areas of the body (thighs, lower abdomen, and buttocks) can be affected by contact with oil-saturated clothing. Although the lesions are commonly called oil boils, they almost never develop from bacteria present in the oils.

Any form of occupational acne or preexisting or coexisting acne vulgaris (nonoccupational) can be aggravated by heat (acne tropicalis and aestivalis); constant friction (acne mechanica), with acne localized to the forehead (hard hat), waist (belt), or other area; excessive scrubbing with harsh soaps (acne detergicans); cosmetics (acne cosmetica); pomade and vaseline (pomade acne); and topical corticosteroids (steroid rosacea). Acneiform eruptions from systemic med-

Table 3–E. ***Some Causes of Occupational Acne***

Petroleum and its derivatives (crude oil and fractious cutting oils)
Coal tar products (coal tar oils, pitch, creosote)
Halogenated Aromatic Compounds (chloracnegens)
Polyhalogenated naphthalenes
Polyhalogenated biphenyls (PCBs, PBBs)
Polyhalogenated dibenzofurans
Contaminants of polychlorophenol compounds especially herbicides (2,4,5-T and pentachlorophenol) and herbicide intermediates (trichlorophenols), e.g., dioxin
Contaminants of 3,4-dichloroaniline and related herbicides (Propanil and Methazole), azo- and azoxybenzenes

ication containing bromides, iodides, and corticosteroids and the syndrome of senile or solar comedones on the face are also to be considered in the differential diagnoses.

Coal tar oils, creosote, and pitch can produce extensive acne in coal tar facility workers, roofers, and road maintenance and construction workers. Comedones are typical of this form of acne. Phototoxic reactions involving both the skin and eye (keratoconjunctivitis) can complicate the picture and produce coal tar melanosis and exacerbations of the acne. Pitch keratoses and acanthomas (precancerous and cancerous skin lesions) can develop later.

Certain halogenated aromatic chemicals (some chloronaphthalenes, PCBs and dibenzofurans, dibenzo-p-dioxins, and chlorobenzenes) are the most potent acnegens and are among the most toxic environmental chemicals. These chemicals can produce chloracne, a type of acne that is often resistant to therapy, and can be accompanied by systemic toxicity. Chloracne is one of the most sensitive indicators of biological response to these chemicals, and acts as a marker of the medical and environmental impact of contamination of technical-grade chemicals with potentially highly toxic intermediates.

Pigmentary Abnormalities

Pigmentary abnormalities can result from exposure to certain chemical, physical, and biological agents. They not only represent difficult cosmetic problems, but can indicate exposure to potential systemic toxins. Differentiation from various nonoccupational, genetic, metabolic, endocrine, inflammatory, and neoplastic pigmentary conditions is necessary.

HYPERPIGMENTATION

Hyperpigmentation (skin darkening) can follow almost any dermatitis as a postinflammatory event. Chemical photosensitizers (tar, pitch, plant, and drug photosensitizers), physical agents (ultraviolet light and thermal and ionizing radiation), and trauma (chronic itching) are common causes. Exposure to certain chemicals (arsenic and acnegenic aromatic hydrocarbons) can also cause hyperpigmentation.

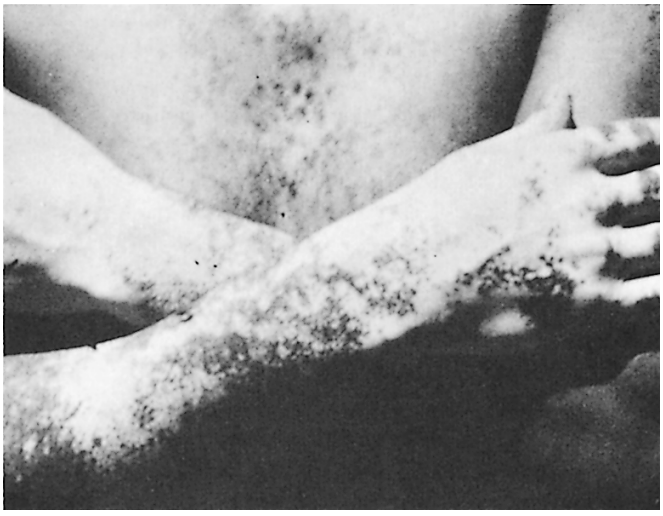

Figure 3–6. Pigment loss in the skin (hypopigmentation) was caused by exposure to a known depigmenting chemical.

HYPOPIGMENTATION

Pigment loss can also follow inflammation (Figure 3–6). Physical or chemical damage to the skin from thermal, ultraviolet, radiation, or chemical burns may cause not only loss of pigment, but also scarring. These changes usually pose no diagnostic problem.

However, pigment loss from certain chemical exposures can be difficult to differentiate from idiopathic vitiligo (a patchy loss of pigment from otherwise healthy skin). Occupational leukoderma (white skin) of this type was first reported from exposure to monobenzyl ether of hydroquinone (agerite alba), once used as an antioxidant in industrial gloves. During the past 20 years, a number of phenolic compounds have caused leukoderma among exposed workers. Sources include hospital and industrial germicidal cleaners, metalworking fluids, oils, latex glues, inks, paints, and plastic resins. Table 3–F lists some of these compounds. These chemicals interfere with melanin pigment biosynthesis, destruction, or both. Hands and forearms are usually affected, although covered parts can also be affected, possibly from ingestion or inhalation of the chemicals.

Sweat-Induced Reactions, Including Miliaria and Intertrigo

Miliaria (prickly heat or heat rash) results from obstruction of sweat ducts and is an inflammatory reaction to retained extravasated sweat. It is a common reaction of people who sweat profusely while exposed to heat. The lesions consist of pinpoint to pinhead-sized papules and vesicles (blisters) on the chest, back, and submammary, inguinal, and axillary folds.

Intertrigo represents maceration that occurs on apposing skin surfaces and is a scaling, erythematous eruption. Superimposed yeast or superficial fungal infection can also be present. Obesity and heat exposure are aggravating factors.

Cutaneous Tumors

Neoplastic growths of the skin are classified as benign lesions, precancers, or cancers. Benign viral warts (*verrucae*

Table 3–F. ***Some Chemicals Producing Occupational Leukoderma***

Monobenzyl ether of hydroquinone
Monomethyl ether of hydroquinone
Hydroquinone
P-Tertiary amyl phenol
P-Tertiary butyl phenol
P-Tertiary butyl catchol
Alkyl phenols
Selected other phenolic compounds

vulgaris) are more common among workers in certain occupations associated with wet work (such as butchers). Keratoacanthomas can be occupationally associated with exposure to sunlight or contact with various tars, pitch, and oils (pitch warts and acanthomas). Although classed as benign lesions, keratoacanthomas can be extremely difficult to differentiate clinically and pathologically from squamous cell carcinoma. Pitch and tar warts (keratoses) and acanthomas can be premalignant lesions.

Excessive exposure to sunlight is the most common cause of precancers and cancers in human skin. Additionally, inorganic arsenic compounds, polycyclic aromatic hydrocarbon compounds associated with asphalt, paraffins, coal tars, oils (creosote, shale, hydrogenated, petroleum, insoluble cutting, and mineral), and ionizing radiation can cause cancer of the skin and other organs. Precancerous actinic keratoses (caused by rays of light that produce chemical effects) appear in sun-exposed areas, can be extensive in workers with outdoor jobs (such as utility line workers, agricultural workers, construction workers, ranchers, fishermen, and sailors), and can progress to squamous cell and basal cell carcinomas. Such workers often have other signs of sun exposure from solar degeneration of collagen, including hyperpigmentation, thin and wrinkled skin, and telangiectasia (a spider-like growth composed of blood or lymph vessels). Epidemiological studies show that sunlight can also be a factor in the increased incidence of malignant melanoma. Skin biopsy is absolutely essential for the diagnosis of all types of skin cancer.

Ulcerations

Tissue injury on a skin or mucous membrane surface can result in erythema, blisters, or pustules, which may result in necrosis and ulceration. This can be caused by trauma, thermal or chemical burns, cutaneous infection, and a number of chemicals, including certain chromium, beryllium, nickel, and platinum salts, calcium oxide, calcium arsenate, calcium nitrate, and strong acids. Cutaneous tumors can also ulcerate. Self-inflicted or unintentionally produced skin disorders commonly appear as ulcerations.

Granulomas

These represent chronic, indolent areas of inflammation and can be localized or generalized. Scar formation often results. Causes include a variety of bacterial (anthrax), mycologic (sporotrichosis), viral (herpes simplex), parasitic (prototheocosis), and botanical (thorns) sources. Other causes include minerals (silica, beryllium, zirconium), bone, chitin, and grease.

Alopecia

Alopecia (absence of hair from the skin areas where it is normally present) has many causes: trauma, cutaneous and systemic disease, drugs, chemicals, and other physical factors, including ionizing radiation. Industrially caused hair loss is rare and the differential diagnosis is long. Chemicals or medications can cause extensive hair shedding by precipitating telogen (resting hair) development, directly poisoning the anagen (growing) hair, or acting in other unknown ways. Other alopecia-producing chemicals include thallium (rodent poison) and boric acid. Medications, primarily cancer chemotherapeutic agents, can precipitate anagen hair loss (immediate loss). Drugs capable of causing telogen hair loss (delayed loss) include oral contraceptives, anticoagulants, propranolol, and thallium.

Nail Disease

Chronic inflammation of the folds of tissue surrounding the fingernail (paronychia), with associated nail dystrophy, is a common occupational disorder associated with wet work (bartenders, maintenance workers, and kitchen workers). This disorder is commonly associated with *Candida* species, *Pseudomonas* species, other bacteria, or dermatophyte fungi.

Nail discoloration can result from exposure to chemicals such as bichromates (accompanied by nail dystrophy), formaldehyde, certain amines, picric acid, nicotine, mercury, resorcinol, or iodochlorhydroxyquin (Vioform).

Nail dystrophy can also accompany exposure to a number of chemicals, especially solvents; it is also caused by trauma or occupational marks in certain occupations such as weaving and the fur industry. Nail dystrophy can also be secondary to Raynaud's phenomenon, vibratory trauma, and acro-osteolysis.

Systemic Intoxication

A number of chemicals with or without direct toxic effect on the skin itself can be absorbed through it and cause (or contribute to, when a substance is also inhaled) systemic intoxication; the severity depends on the amount absorbed. A partial list of substances and their systemic effects includes the following:

- ➢ Aniline (red blood cells and methemoglobinemia)
- ➢ Benzidine (carcinoma of urinary bladder)
- ➢ Carbon disulfide (nervous system and psychological disturbances)
- ➢ Carbon tetrachloride (central nervous system, or CNS, depression, hepatotoxicity, and nephrotoxicity)
- ➢ Dioxane (CNS depression)
- ➢ Ethylene glycol ethers (CNS depression, pulmonary edema, hepatotoxicity, and nephrotoxicity)
- ➢ Halogenated naphthalenes, diphenyls, and dioxins (neurotoxicity and hepatotoxicity, altered metabolism)
- ➢ Methyl butyl ketone (CNS depression and peripheral neuritis)
- ➢ Organophosphate pesticides (inhibition of enzyme cholinesterase with cardiovascular, gastrointestinal, neuromuscular, and pulmonary toxicity)
- ➢ Tetrachloroethylene (CNS depression, suspected carcinogen)
- ➢ Toluene (CNS depression).

Chemicals whose absorption may contribute to the total exposure are designated with a "Skin" notation in the American Conference of Governmental Industrial Hygienists (ACGIH) book, *Threshold Limit Values for Chemical Substances and Physical Agents* (*TLVs®*) *and Biological Exposure Indices* (*BEIs®*). (Also see Appendix B.) More information can also be found in the ACGIH publication *Documentation of the Threshold Limit Values and Biological Exposure Indices,* 7th ed. Contact the ACGIH for details. Cutaneous absorption here refers to absorption by skin, mucous membranes, and eyes through either airborne or direct contact.

BURNS

Because all burns have essentially the same features, they are usually classified by degree according to depth of injury as first-, second-, or third-degree.

The main types of burns are as follows:

- ➢ Explosion burns, usually affecting exposed areas (hands, face)
- ➢ Steam burns, often superficial on exposed areas (more serious if with eye or respiratory contact)
- ➢ Hot-water burns, often leading to blistering depending on water temperature, more severe if victim is wearing heavy, permeable clothing
- ➢ Molten-metal burns, often affecting lower limbs, often extremely deep with metal encrusted in skin
- ➢ Hot-solid burns, normally not extensive, can be very deep
- ➢ Flame burns, almost always deep, often extensive, with the type of clothing being a major factor in severity
- ➢ Electricity and radiant energy burns, almost always severe, often with complications; ordinary clothing offers little protection

Nature of Chemical Burns

Burns caused by chemicals are similar to those caused by heat. In fact, some chemicals, such as sodium hydroxide, cause not only chemical burns because of their caustic action, but also thermal burns because of the heat they can generate when they react with moisture in the skin. After patients with chemical burns have been given emergency first aid, their treatment is the same as for patients with thermal burns.

Both thermal burns and chemical burns destroy body tissue. Some chemicals continue to cause damage until reaction with body tissue is complete or until the chemical is washed away by prolonged flushing with water. Strong alkalis penetrate tissue deeply, and strong acids corrode tissue with a characteristic stain.

Many concentrated chemical solutions have an affinity for water. When they come in contact with body tissue, they withdraw water from it so rapidly that the original chemical composition of the tissue (and hence the tissue itself) is destroyed. In fact, a strong caustic may dissolve even dehydrated animal tissue. The more concentrated the solution, the more rapid is the destruction.

Sulfuric, nitric, and hydrofluoric acids are the most corrosive of the inorganic acids, even more corrosive than hydrochloric acid. Some chemicals, such as phenol, are doubly hazardous. In addition to being highly corrosive, they are poisonous when absorbed through the skin. The severity of chemical burns depends on the following factors:

- ➢ Corrosiveness of the chemical
- ➢ Concentration of the chemical
- ➢ Temperature of the chemical or its solution
- ➢ Duration of the contact

The first three factors are determined by the very nature of the chemical and the requirements of the process in which it is used. The fourth factor, duration of the contact, can be controlled by the proper first-aid treatment administered without delay.

Classification of Burns

Burns are commonly classified as first-, second-, or third-degree. Second-degree burns may be further classified as superficial or deep dermal. However, for purposes of this chapter, the common classifications of first-, second-, and third-degree are adequate and are described here.

FIRST-DEGREE BURNS

These are characterized by redness and heat accompanied by itching, burning, and considerable pain. Only the outer layer of the epidermis is involved.

SECOND-DEGREE BURNS

These are highly painful and involve deeper portions of the epidermis and the upper layer of dermis. Generally, the skin is mottled red with a moist surface and blisters form. Such burns are easily infected.

THIRD-DEGREE BURNS

These are very severe forms of injury, involving loss of skin and deeper subcutaneous tissue. They are pearly-white or charred in appearance and the surface is dry. They are not exceedingly painful at first because nerve endings are usually impaired or destroyed.

SPECIAL TYPES OF BURNS

Cement and hydrofluoric acid deserve special mention. Recently, there have been many reports of severe burns from kneeling in wet cement or from wet cement becoming trapped inside boots. Pressure and occlusion are important factors, as well as the need to work fast with premixed cement, which can encourage prolonged contact. Symptoms may be delayed, so workers must be alert to the danger. Adherent cement should be removed by copious and gentle irrigation with water.

Hydrofluoric acid is one of the strongest acids known and is widely used in industry. Hydrofluoric acid burns are characterized by intense pain, often delayed, and progressive deep tissue destruction (necrosis). Immediate treatment

with topical magnesium sulfate or benzalkonium chloride and calcium gluconate gels and injections is recommended.

Complications of Burns

The dangers to life that result from extensive burns are infection (which causes most burn complications), loss of body fluid (plasma or lymph from the blood), and subsequent shock. Finally, the functional, cosmetic, and psychological sequelae may require the full attention of a rehabilitation team.

DIAGNOSIS

Anyone who works can develop a skin disorder, but not all skin disorders occurring in the workplace are occupational. Arriving at the correct diagnosis is not generally difficult, but it is more than a routine exercise. The following criteria are generally used.

Appearance of the Lesion

The dermatosis should fall into one of the accepted clinical types with respect to its morphological appearance.

Sites of Involvement

Common sites are the hands, wrists, and forearms, but other areas can be affected. Widespread dermatitis can indicate heavy exposure to dust because of inadequate protective clothing or poor hygiene habits.

History and Course of the Disease

A thorough and pertinent clinical history is the most important aspect in diagnosis of occupational dermatoses. This includes a description of the eruption, response to therapy, medical history and review of systems, a detailed work history (description of present and past jobs, moonlighting, preventive measures, cleansers, and barrier creams), and a detailed description of nonoccupational exposures. The behavior of the eruption on weekends, vacation, and sick leave can be very helpful in assessing the occupational component.

Ancillary Diagnostic Tests

When indicated, selected laboratory tests and office procedures are used for detecting skin disorders. These may include direct microscopic examination and bacterial and fungal cultures of the skin, skin biopsy for histopathological diagnosis, and patch tests and photopatch tests to detect any occupational or nonoccupational allergens and photosensitizers. Patch tests should be performed by physicians experienced with the procedure.

Treatment

Therapy of occupational skin disorders is essentially no different from that of the same nonoccupational disorder. However, two key factors are often overlooked when a worker's skin clears and he or she returns to work: identifying the cause of the disease and preventing a recurrence. Patients with skin disorders not responding to initial treatment should be referred for specialty evaluation.

WORKERS' COMPENSATION

State workers' compensation laws are no-fault statutes that hold employers responsible for the cost of occupational injury and disease claims while guaranteeing benefits to covered workers who meet the laws' requirements. All states now recognize responsibility for occupational diseases, and health professionals should become familiar with their own state workers' compensation laws and regulations. The American Medical Association's *Guides to the Evaluation of Permanent Impairment* is mandated, recommended, or often used by authorities in 40 of 53 jurisdictions (38 states and 2 territories). In general, three types of payment may be made when a claim is approved: temporary total disability payments to compensate for lost wages, payment of medical bills, and payment for permanent partial or permanent total disability.

Most claims based on occupational skin disease involve temporary total or permanent partial disability. Temporary total disability usually ceases when the patient has reached maximum medical improvement, has a valid job offer within his or her physical capabilities, or actually returns to work. Some states allow third-party liability suits arising out of workers' compensation cases.

EVALUATION OF OCCUPATIONAL DERMATOSES FOR WORKERS' COMPENSATION

In the evaluation of workers' compensation cases, the key elements are diagnosis, causation, impairment, and conclusions and recommendations.

Diagnosis

An accurate diagnosis of the claimant's condition is imperative. This often involves obtaining a detailed history of the present illness, reviewing of work exposures including material safety data sheets, and, whenever possible, visiting the workplace. Evaluation of the cutaneous findings should include an examination of the skin and skin biopsies, cultures, patch testing, or other ancillary tests if warranted. If diagnosis is in doubt, specialized consultation is warranted.

Causation

Determination of the cause-and-effect relationship between a skin disorder and an occupation is not always clear-cut. Questions to be considered include the following:

- ➢ Is the clinical appearance compatible with an occupational dermatosis?
- ➢ Are there workplace exposures to chemical, physical, mechanical, or biologic agents that may affect the skin?

- ➢ Is the anatomic distribution of the eruption compatible with job exposure? Many occupational dermatoses involve the hands.
- ➢ Is the temporal relationship between exposure and onset consistent with an occupational skin disease?
- ➢ Have nonoccupational exposures been excluded as causes?
- ➢ Does the dermatitis improve away from work exposure to the suspected agent(s)?
- ➢ Do patch or provocation tests identify a probable cause?

A "yes" answer to at least four of these questions is probably adequate to establish probable cause.

Impairment Evaluation

As a prelude to impairment evaluation, the physician must determine the impact of the medical condition on life activities and the stability of the condition. If the worker has a new or recent onset condition that significantly precludes working on the current job, then temporary total impairment may exist and an appropriate amount of time away from work may be warranted under most workers' compensation laws. Unduly restrictive limitations, such as avoiding all contact with a particular substance, may jeopardize a worker's job; before writing such recommendations, the physician should generally discuss them with the worker and employer.

The AMA's *Guides to the Evaluation of Permanent Impairment* are used to evaluate *permanent* impairment of any body system(s), from both occupational and nonoccupational causes; they are not designed for use in evaluating *temporary* impairment. They are guidelines, are not absolute recommendations, and are designed to bring objectivity to an area of great subjectivity. The *Guides* include clinically sound and reproducible criteria useful to physicians, attorneys, and adjudicators. They espouse the philosophy that all physical and mental impairments affect the whole person. A 95–100 percent whole person impairment is considered to represent almost total impairment, a state that is approaching death. Before using the *Guides* for evaluating cutaneous impairment, the health professional should read the two introductory chapters, the glossary and then Chapter 8, The Skin. Chapter 2, Practical Applications of the *Guides,* lists a suggested outline for a medical evaluation report.

Permanent impairment of the skin is "any dermatologic abnormality or loss that persists after medical treatment and rehabilitation and that is unlikely to change significantly in the next year, with or without medical treatment" (p. 173, *AMA Guides to the Evaluation of Permanent Impairment,* 5th ed., 2000). The *Guides* popularized the concept that impairment is a medical issue assessed by medical means, in contrast to disability, which is a nonmedical assessment generally determined by adjudicating authorities.

Disability is defined as an "alteration of an individual's capacity to meet personal, social, or occupational demands or to meet statutory or regulatory requirements because of an impairment," (p. 8, *AMA Guides to the Evaluation of Permanent Impairment,* 5th ed., 2000). It is important to remember that an impaired person is not necessarily disabled. The classic example often cited is that of two people who lose the distal portion of the phalanx of the same finger. Although impairment for both people is the same, disability is likely to be greater for a concert pianist than for a bank president.

The AMA chapter on the skin lists five classes of impairment, ranging from 0 percent to 95 percent (Table 3-G.)

The impact of the disorder on the activities of daily living should be the major consideration in determining the class of

Table 3–G. ***Criteria for Rating Permanent Impairment Due to Skin Disorders****

Class 1: 0%–9% Impairment of the Whole Person	Class 2: 10%–24% Impairment of the Whole Person	Class 3: 25%–54% Impairment of the Whole Person	Class 4: 55%–84% Impairment of the Whole Person	Class 5: 85%–95% Impairment of the Whole Person
Skin disorder signs and symptoms present or intermittently present	Skin disorder signs and symptoms present or intermittently present	Skin disorder signs and symptoms present or intermittently present	Skin disorder signs and symptoms constantly present	Skin disorder signs and symptoms constantly present
and	**and**	**and**	**and**	**and**
no or few limitations in performance of activities of daily living; exposure to certain chemical or physical agents may temporarily increase limitation	limited performance of some activities of daily living	limited performance of some activities of daily living	limited performance of many activities of daily living, including intermittent confinement at home or other domicile	limited performance of most activities of daily living, including occasional to constant confinement at home or other domicile
and	**and**	**and**	**and**	**and**
requires no or intermittent treatment	may require intermittent to constant treatment	may require intermittent to constant treatment	may require intermittent to constant treatment	may require intermittent to constant treatment

* The signs and symptoms of disorders in classes 1, 2 and 3 may be intermittent and not present at the time of examination. Consider the impact of the skin disorder on the ability to perform activities of daily living in determining the class of impairment. Consider the frequency and intensity of signs and symptoms (i.e., severity) and the frequency and complexity of medical treatment when selecting an appropriate impairment percentage and estimate within any class. (Source: *Evaluation of Permanent Impairment,* 5th Edition. American Medical Association, copyright 2000.)

impairment. The frequency and intensity of signs and symptoms and the frequency and complexity of medical treatment should guide the selection of an appropriate impairment percentage and estimate within any class.

The activities of daily living (ADLs) include self-care and personal hygiene, communication, physical activity, sensory function, hand functions (grasping, holding, pinching, percussive movements, and sensory discrimination), travel, sexual function, and sleep. Other examples of specific ADLs are listed in the glossary of the *Guides*.

The examples within each class are very important guides for the first time user. It is critically important to remember that impairment is not determined by diagnosis alone, but also by the effect of the disease on ADLs along with the frequency and intensity of disease and the frequency and complexity of therapy. Most cutaneous impairment falls within the first three classes ranging from 0 percent to 54 percent.

Unique to the *Guides'* skin chapter are the discussions of pruritus (itching), disfigurement, scars and skin grafts, and patch testing. Itching is evaluated by determining its interference with the ADLs and the extent to which the description of pruritus is supported by objective findings such as lichenification, excoriation, or hyperpigmentation. Disfigurement usually involves no loss of body function and little or no effect on the ADLs. Disfigurement may well impair self-image, cause life-style alteration, and result in social rejection. These changes are best evaluated in accordance with the criteria in the chapter on mental and behavioral conditions. Evaluation of scars and skin grafts is made according to the impact on ADLs. When impairment is based on peripheral nerve dysfunction or loss of range of motion, it may be evaluated according to the criteria in the chapters on the nervous system and musculoskeletal system. When properly performed and interpreted, patch tests can make a significant contribution to the diagnosis of allergic contact dermatitis

Conclusions and Recommendations

All diagnoses should be listed and summarized. A summary statement regarding causation is then made that states whether, within a reasonable degree of medical certainty, the disease is related to work. The diagnosis should include a description of specific clinical findings related to the impairment and how they relate to and compare with the criteria in the *Guides*. The impairment value also should be explained. Specific recommendations for therapy should be included along with a brief explanation of the treatment. Recommendations for prevention, including work restrictions, are next; possible suggestions are environmental modification (exhaust ventilation, splash guards) and personal protective equipment. The effect of future exposures to chemical, physical, and biological agents should be addressed, along with any need for rehabilitation. In conclusion, impairment evaluation is an important and sometimes daunting task for physicians evaluating workers with putative occupational diseases.

Physical Examinations

Preplacement examinations will help identify those who may be especially susceptible to skin irritations. The physician in charge of the examination should be provided with detailed information regarding the type of work for which a person is being considered.

Routine use of preplacement patch tests to determine sensitivity to various materials is not recommended. Patch tests cannot predict whether new workers will become sensitized to certain materials and develop dermatitis, but only tell whether people who have previously worked on similar jobs are sensitized to the chemicals with which they have worked.

The industrial physician has the primary responsibility for determining whether an applicant may be predisposed to skin irritations and for recommending suitable placement on the basis of these findings. Nevertheless, considerable responsibility also may fall to the safety and personnel departments, supervisors, industrial hygienists, and other people functionally responsible for accident prevention work and control of industrial diseases.

Care should be taken in restricting people who are not specifically sensitive to the agents involved in the job just because of a history of skin trouble unless there is active skin disease at the time of placement. In many cases, the physician is limited to simply counseling the person about risk.

PREVENTION AND CONTROL

Dermatoses caused by substances or conditions present in the work environment are largely preventable, but only through the combined effort of management and workers. This type of combined effort is best demonstrated in large industrial firms.

There are two major approaches to the prevention and control of occupational diseases in general and dermatoses in particular: environmental control measures and personal hygiene methods. In both cases, the key is cleanliness, both environmental and personal.

Environment

Environmental cleanliness includes good housekeeping (discussed later in this section). Its primary function in preventing industrial dermatitis (and other industrial diseases) is to reduce the possibility of contact with the offending agent.

PLANNING

Proper design of equipment during construction is of great importance in the reduction of dermatitis and other industrial health problems. Ventilation must meet the industry requirements.

Provisions must be made for the safe handling of irritant chemicals. Pumps, valves, pipes, fittings, and the like must be maintained to eliminate (as much as possible) the contact of workers with irritants. Empty drums or bags used to

transport incoming materials of a hazardous nature should be properly disposed of to prevent accidental exposure. Containers being readied for shipment should be filled in a manner that prevents contact with workers and left clean so that truckers, warehouse workers, and others cannot accidentally contact a harmful material on contaminated surfaces. Containers with harmful materials should be labeled with proper precautions.

PROCESS CONTROL

Before any new process or work procedure is introduced and before new substances are adopted in an established process, an industrial hygienist or chemist should carefully consider every aspect of the operation for possible or known dermatitis hazards, including those that can be caused by trace impurities. Analyzing work procedures and processes often requires specialized equipment and techniques.

Once the potential dermatitis-causing factors have been determined, suitable engineering controls can be instituted and built into the work processes or operations.

The best way of controlling dermatitis is to prevent skin contact with offending substances; if there is no exposure, there will be no dermatitis. Unfortunately, this is more easily said than done.

Operations should be planned and engineered to ensure minimal worker contact with irritants and sensitizing chemicals. When possible, chemicals of low toxicity and low irritant potential should be substituted. Enclosure guards and mechanical handling facilities may be necessary when an operation involves highly corrosive materials. Operations that give off dust, fumes, or vapors need suitable exhaust ventilation to minimize exposure. Low ambient relative humidity in the workplace may cause or contribute to some occupational skin diseases.

SELECTION OF MATERIALS

Much can be done to minimize hazardous conditions through careful selection of materials. Dry sodium and potassium hydroxide, for example, are now available in virtually dust-free forms; for many uses, they can be purchased in solution and handled with pumps. Other products are available as prills (beads), pellets, granules, or solutions that do an adequate job and reduce the dust hazard. Concentrated solutions are also finding favor not only for safety, but for economy in handling.

Some compounds can be successfully used when the percentage of the irritant in the compound is reduced. In other cases, a less irritating or nonirritating material, or a less sensitizing material, can be substituted. The supplier should be asked to provide a closely related and generally satisfactory substitute for the irritating or sensitizing material. Examples include substituting one germicide for another in metalworking fluids when an allergy to the first germicide is found and using vinyl gloves in place of rubber gloves if a rubber allergy is found.

Monitoring and Control Technology

In order to correctly measure and sample skin exposure to chemicals, it is important to understand the methods of such exposure. These include contact with chemicals in a container (spill), contact with contaminated surfaces (tools or rags), exposure to aerosols (fallout of mist or soluble powder), exposure to sprays (ballistic droplets versus mist), and permeation through clothing (protective and personal). Other factors to be considered in the evaluation of skin exposure to chemicals include variable deposition rates onto the body, the effect of clothing, duration of skin contact with the chemical, and time of skin retention and permeation through the skin.

SAMPLING PROCEDURES

Current sampling procedures are often difficult to apply to prevention of occupational skin disease. Some exceptions include use of wipe samples for chemical analysis, hand or skin rinses, dermal dosimeters or patches, sampling cotton socks when shoe contamination is suspected, and sampling air inside a suit when the air is contaminated. Air levels of dusts and chemicals may have some limited application. The use of fluorescent tracers, fiber-optic luminescence skin monitoring, and charcoal cloth absorptive padosimeters are currently being evaluated. Color-indicator soaps have been used to detect exposure to tetryl (used in munitions facilities) and mercury. A scientific study established methods to determine relative benefits of equipment such as gloves and clothing to protect skin against styrene in a reinforced plastics facility. Another study dealt with the biological surveillance of workers exposed to dimethylformamide and the influence of skin protection on its percutaneous absorption. Standardized techniques have improved measurement of the effectiveness of protective material such as gloves and clothing against carcinogens and polychlorinated biphenyls.

GOOD HOUSEKEEPING

Environmental cleanliness is nothing more than good housekeeping and it is maintained by frequently cleaning floors, walls, ceilings, windows, and machinery. Good housekeeping work is usually performed by a special maintenance group that is given direct responsibility for maintenance cleaning. In order to be effective, cleaning should be part of a plan and should be performed on schedule. The necessary equipment and materials to do the most effective job possible in a reasonable amount of time should be assigned, and housekeeping workers should be trained so that they perform their operations efficiently and safely.

Environmental cleanliness is important to maintain good morale, reduce contact dermatitis, and set an example for workers. Floors, walls, ceilings, and light fixtures should be cleaned regularly in order to maintain the best possible conditions in the facility. (The requirements of Part 1910 of the Occupational Safety and Health Standards, Section 1910.14, "Sanitation," contain details on housekeeping, waste disposal,

vermin control, water supply, toilet facilities, washing facilities, change rooms, consumption of food and beverages on premises, and food handling.) As pointed out in the OSHA standards, washrooms, showers, toilets, and locker rooms should be kept clean and sanitary.

Many types of cleaners are available, from simple cleaning agents to complex formulations. These come in solid, liquid, or paste, and contain cleaners and sanitizing agents using synthetic detergents, soaps, and alkaline salts in combinations. Some mixtures include sanitizing agents to help prevent the spread of bacteria, fungi, and other biological agents. Environmental cleanliness and good housekeeping are also beneficial because they set an example for the workers and encourage personal cleanliness.

Personal Cleanliness

The importance of personal cleanliness in the prevention and control of occupational dermatoses cannot be overemphasized. When investigating contact dermatitis, one should also consider the possibility of irritants contacted at home or with a hobby.

PREVENTION OF CONTACT

When facility and process design cannot eliminate all contact with irritants, personal protective equipment must be used. Included are gloves, gauntlets, aprons, and boots made of a material that is impervious to the particular substance. These, along with goggles, afford sufficient protection in most cases. Disposable gauntlets, aprons, boots, and gloves are available, but they are more subject to tears than heavier safety gear. Other gear may provide insulation against heat or light. All personal protective equipment required for a job should be carefully maintained and replaced when it becomes worn.

In order to minimize contact with harmful agents, workers must have access to facilities for washing hands and be furnished with other means of keeping clean. It is up to the employer to provide adequate washing facilities, good cleansing materials, and education on the need for good hygiene practices. Washbasins must be well-designed, conveniently located, and kept clean; otherwise they will be used infrequently, if at all. The farther workers must walk to clean up, the less likely they are to do so. Inconveniently located washbasins invite such undesirable practices as washing with more easily available solvents, mineral oils, or industrial detergents, none of which is intended for skin cleansing. For workers to keep their skin reasonably free of injurious agents, they must use washing facilities at least four times a day: during work (before eating, drinking, smoking, or using the restroom), before lunch, after lunch, and before leaving the facility (see Figure 3–7).

Those who work with toxic chemicals and radioactive substances must receive specific safe handling instructions and should take a shower after their work shift and change their clothing. Workers should be instructed in specific procedures for cleanliness. They should be told where, how, and when to wash and should be given sufficient time to wash, advised that they will be rated on this part of their job performance, and informed of the possible health hazards involved.

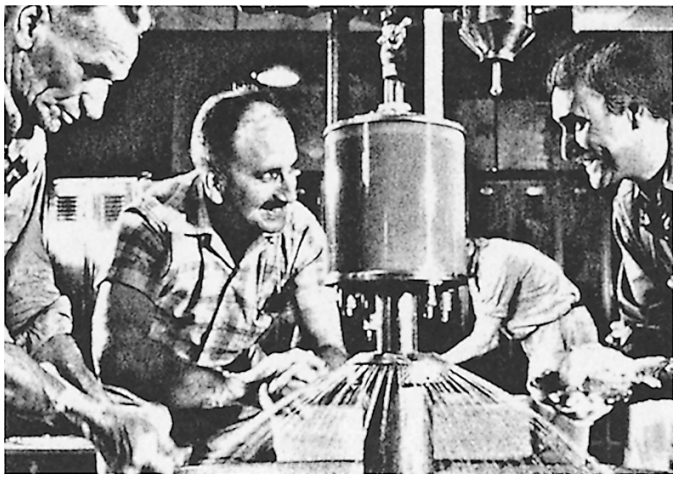

Figure 3–7. Wash facilities should be conveniently located and should be adequate for all needs.

For many exposures, frequent washing alone is a successful preventive, particularly when the dermatitis is caused by plugging of the pores, as from dust. In all cases, however, the use of large quantities of water on the skin following exposure to irritants is necessary. Safety showers and eyewash fountains should be available, and flushing should continue for at least 15 minutes.

It may be advisable in some instances to use neutralizing solutions after a thorough flushing with water. However, because some neutralizing solutions are themselves irritants, they should be used only on the advice of a physician.

The type of soap used is important. Even a generally good soap can cause irritation on certain types of skin. Harsh mineral abrasives can cause dermatitis in many people.

The choice of a good soap may in some cases involve technical considerations, which are better left to the medical department or other qualified department than to laypeople. The basic requirements of industrial skin cleansers are as follows:

- ➢ They should remove industrial soil quickly and efficiently.
- ➢ They should not harmfully dehydrate, abrade, or irritate the skin by normal application.
- ➢ They should flow easily through dispensers.
- ➢ They should be adequately preserved against microbial contamination.

Additional desirable qualities include the following:

- ➢ They should have aesthetic appeal (color and odor).
- ➢ They should have good foaming qualities.

A number of cases of industrial dermatitis are reported to be caused not by substances used in the workplace, but by cleansing materials used to remove those substances. A worker may be inclined to wash the hands with the cleaning agents that are most available and work the fastest, but these

are often dermatitis-producing solvents. Overuse of waterless cleansers can irritate and dry the skin. Generally, workers should apply a good hand lotion after applying waterless cleansers.

The installation in work-area washing places of soap-dispensing units containing properly selected cleansing agents has proved to be a valuable measure. Such units should be placed in convenient locations, and enough of them should be provided to accommodate all employees who are exposed to skin irritants. Where soap-dispensing units are furnished, workers should be required to use them.

BARRIER CREAMS

A barrier cream is the least effective way of protecting skin (Figure 3–8). However, there are instances when a protective cream may be used for preventing contact with harmful agents when the face cannot be covered by a shield or gloves cannot be worn (Figure 3–9). Several manufacturers compound a variety of products, each designed for a certain type of protective purpose. Thus, there are barrier creams that protect against dry substances and those that protect against wet materials. Using a barrier cream to protect against a solvent is not as effective as using an impervious glove; however, there are compounds that offer some protection against solvents when applied with sufficient frequency.

Barrier creams and lotions should be used to supplement, but not to replace, personal protective equipment. Protective barrier agents should be applied to clean skin. When skin becomes soiled, both the barrier and any soil should be washed off and the cream reapplied.

Three main types of barrier creams and lotions are available.

Vanishing cream usually contains soap and emollients that coat the skin and cover the pores to make subsequent cleanup easier.

Water-repellent cream leaves a thin film of water-repellent substance such as lanolin, beeswax, petrolatum, or silicone on the skin, and helps to prevent ready contact with water-soluble irritants such as acids, alkalis, and certain metallic acids. Remember, however, that the protection may not be complete, especially when the barrier has been on the skin for some time. Alkaline cleaning solutions tend to emulsify and remove the barrier rapidly, thus leaving the skin unprotected.

Solvent-repellent creams contain ingredients that repel oil and solvent. Lanolin has some oil-repellent and water-repellent properties and can be used as an ingredient. There are two types of solvent-repellent barrier preparations; one leaves ointment film and the other leaves a dry, oil-repellent film. Sodium alginates, methyl cellulose, sodium silicate, and tragacanth are commonly used. Lanolin offers some protection against oils as well as water.

Special types. In addition to these three main types, a number of specialized barriers have been developed. Creams and lotions containing ultraviolet screening and blocking agents are used to help prevent overexposure to sun or other ultraviolet sources. Others have been developed to afford protection

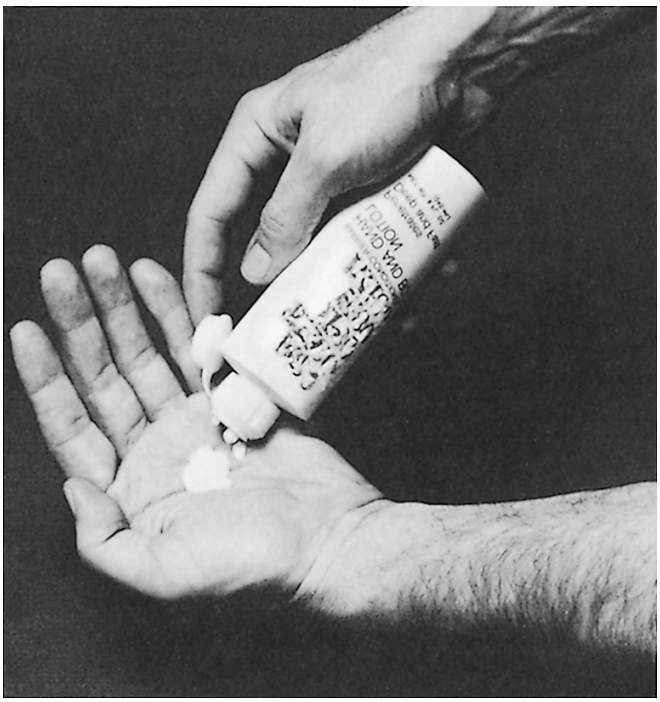

Figure 3–8. Barrier cream is applied by an employee before starting work and is washed off before lunch; it is reapplied after lunch and washed off before the worker leaves. Barrier cream is the least effective way of protecting the skin.

Figure 3–9. Most glove manufacturers provide a hand protection counseling service. They assess hazards and match them with gloves or other devices. It is up to the employer to educate employees to use the proper protection for the job performed.

from such diverse irritants as insects, gunfire backflash, and poison oak dermatitis.

Personal Protective Equipment

CLOTHING

Whenever irritating chemicals are likely to contaminate clothing, care must be taken to provide clean clothing at least daily. Because workers' families have developed contact dermatitis or chloracne from contact with clothing worn home from the job, clothing worn on the job should not be worn at home. Clothing contaminated with chemicals should always be thoroughly laundered before it is worn again. Clothing contaminated on the job should be changed at once.

PROTECTIVE CLOTHING

Sometimes handling irritant, allergenic, or toxic materials cannot be avoided; in this situation, protective clothing may provide a good barrier against exposure. OSHA requirements for "Personal Protective Equipment" (PPE) are described in 29 *CFR* Part 1910, Subpart 1, which includes general requirements on indications for use, ensuring adequacy of employee owned equipment and safe design of PPE for the work to be performed. This section was amended in 1994 to include requirements for hazard assessment and equipment selection, a ban on defective equipment, detailed training requirements and revised sections on protection of the eyes and face (1910.133), head (1910.135), feet (1910.136), and hands (1910.138). The American National Standards Institute has also issued a new standard (ANSI/ISEA 105) for hand protection (see also the section on "Gloves" in this chapter. Other protective clothing requirements appear in standards covering specific hazards (bloodborne pathogens) and specific occupations (shipyard workers).

High-quality clothing should be obtained. Manufacturers provide a large selection of protective garments made of rubber, plastic film, leather, cotton, or synthetic fiber that are designed for specific purposes. For example, there is clothing that protects against acids, alkalis, extreme exposures of heat, cold, moisture, and oils. When such garments must be worn, management should purchase them and enforce their use. Management should make sure that the clothing is mended and laundered often enough to keep it protective. If work clothes are laundered at home, the worker's other clothes may be contaminated with chemicals, glass fiber, or other dusts.

Closely woven fabrics also protect against irritating dust. Gloves and aprons of impervious materials (such as rubber or plastic) protect against liquids, vapors, and fumes (Table 3–H). Natural rubber gloves, aprons, boots, and sleeves are impervious to water-soluble irritants, but soon deteriorate if exposed to strong alkali and certain solvents.

Synthetic rubbers, such as neoprene and many of the newer plastics, are more resistant to alkalis and solvents than natural rubber; however, some materials are adversely affected by chlorinated hydrocarbon solvents. The protection used should be based on the particular solvents that are used. For workers who wear rubber or plastic, the irritant will eventually penetrate and

Table 3–H. ***Physical Performance Chart of Selected Glove Materials***

Coating	*Abrasion Resistance*	*Cut Resistance*	*Puncture Resistance*	*Heat Resistance*	*Flexibility*	*Ozone Resistance*	*Tear Resistance*	*Relative Cost*
Natural rubber	E	E	E	F	E	P	E	Medium
Neoprene	E	E	G	G	G	E	G	Medium
Chlorinated polyethylene (CPE)	E	G	G	G	G	E	G	Low
Butyl rubber	F	G	G	E	G	E	G	High
Polyvinyl chloride	G	P	G	P	F	E	G	Low
Polyvinyl alcohol	F	F	F	G	P	E	G	Very high
Polyethylene	F	F	P	F	G	F	F	Low
Nitrile rubber	E	E	E	G	E	F	G	Medium
Nitrile rubber/Polyvinyl chloride (Nitrite PVC)	G	G	G	F	G	E	G	Medium
Polyurethane	E	G	G	G	E	G	G	High
Styrene-butadiene rubber (SBR)	E	G	F	G	G	F	F	Low
Fluon (Viton®)	G	G	G	G	G	E	G	Very high

Grip/slip is related to glove surface and is enhanced when the glove is rough.

Dexterity is related to glove thickness and decreases as the glove thickness increases.

KEY TO CHART: E=excellent; G=good; F=fair; P=poor (Ratings are subject to variation, depending on formulation, thickness, and whether the material is supported by fabric).

The listings were taken from various glove manufacturers and NIOSH, and are ONLY A GENERAL GUIDE. When selecting gloves for any application, contact the manufacturer, giving as much information as possible.

This table shows the *physical* properties of selected glove materials. For chemical resistance properties of glove materials see section *Gloves* and published reference guides in that section.

be trapped next to the skin, causing repeated exposure every time the garment is worn. So gloves should be used to protect against splashes and wet items, but will not protect against immersions. Instruments or containers should be used for items that must be immersed. Reusable gloves should be washed according to the manufacturer's instructions.

Disposable paper and plastic garments can also be used for some tasks. Garments are also necessary in sterile areas to keep products from being contaminated (Figure 3–10).

FABRICS

Fabrics without coatings are generally unsuitable as protective clothing for toxic chemical exposures because they are all permeable and have other weaknesses. Cotton and rayon, for instance, are degraded by acids; wool is degraded by alkalis.

GLOVES

Because a high percentage of occupational contact dermatitis cases involve the hands, it is imperative for health and safety professionals to be knowledgeable about the types of glove materials available, their selection and use, and the types of adverse dermatological reactions to gloves.

Glove materials include the following:

- ➢ Natural rubber latex
- ➢ Synthetic rubber latex and synthetic rubber: butyl, chloroprene (Neoprene®), fluon (Viton®), nitrile, styrene-butadiene-styrene, styrene-ethylene-butylene-styrene, polyethylene, and synthetic polyisoprene
- ➢ Plastic polymers: ethylene-methyl methacrylate, polyethylene, polyvinyl alcohol, and polyvinyl chloride
- ➢ Laminated plastic polymers: a laminate of polyethylene-ethylenevinylalcohol copolymer-polyethylene (Silver Shield® and 4 H® gloves)
- ➢ Leather (chrome or vegetable tanned)
- ➢ Textiles: natural or synthetic; woven from fabrics, knit or terry cloth; also may be coated with rubber or plastic; fabric such as cotton or nylon may also be used as glove liners
- ➢ Other materials: wire cloth made of stainless steel or nickel as used by autopsy prosectors

A number of standards, guides, and rules have been published for gloves in both the United States and Europe. Categories of glove standards depend on the type of glove material used, type of work being done, and type of hazard encountered. Parameters of glove performance evaluated include physical strength, dexterity, abrasion, and heat and cold resistance. Other physical resistance factors include cut and puncture resistance, tear and tensile strength, and flammability (see Table 3-H). Resistance to swelling, degradation, permeation, and penetration are some of the more important chemical parameters evaluated; biological resistance to liquids and microorganisms also has been evaluated. Consult the references by Henry (1994) and Mellstrom & Carlsson (1994) for a list of current standards.

Figure 3–10. Protective clothing is worn over work clothes to prevent contamination of both the worker and, in sterile rooms, the product.

The new ANSI/ISEA 105-2000, *American National Sandard for Hand Protection Selection Criteria,* published by the International Safety Equipment Association (ISEA), provides a numeric scale method for manufacturers to rate their products against certain contaminants and exposures. With classification based on this scale, users can make decisions on which gloves are suitable for which tasks. Glove performance

and pass/fail criteria are included for the following hazardous exposures: cut, puncture and abrasion resistance; protection from cold; chemical permeation and degradation; detection of holes; and heat and flame resistance. The standard also includes reference information on special considerations such as biological protection, electrical protection, and radiation hazards. Every end use is different and no single test method can fully replicate the variety of hazards that a worker may encounter. The ISEA suggests that users should contact glove manufacturers for information on the new glove ratings and labeling of their products that meet the standard.

Forsberg & Mansdorf (1997) outline a number of factors to consider in the selection of gloves and other protective clothing:

- ➢ Chemicals ultimately penetrate protective barriers and can do so without evidence of damage to the barrier.
- ➢ Protective equipment cannot be used if torn or damaged.
- ➢ A barrier may protect against a single chemical but not necessarily against a mixture of chemicals.
- ➢ Temperatures higher than room temperature decrease breakthrough time of chemicals. The authors' *Quick Selection Guide* (1997) is based on room temperature data.
- ➢ Generally, thicker materials or layers of material are better for chemical resistance.
- ➢ Beware of lookalikes with chemical protective clothing.
- ➢ If a chemical has penetrated a material, the garment must be decontaminated before reuse. Gloves used in health care must be disposed of properly after each patient contact and cannot be decontaminated.
- ➢ Users of chemical protective clothing should check with their suppliers to confirm the performance standards of their products, to verify information on proper storage and care, and to select materials.

Another critically important factor is safety. Gloves should not be used where they may be caught in machinery, with potential for serious injury or loss of fingers or hands. Safety and health professionals should review any recommendation for glove use by health care providers who may not be familiar with a specific job.

Reference guidelines for the selection of gloves include the following:

- ➢ Schwope AD, et al. *Guidelines for the Selection of Chemical Protective Clothing,* 3rd ed., Vols. I and II. Cincinnati: American Conference of Governmental Industrial Hygienists, 1987. (Prepared by A.D. Little, Inc., for the EPA.)
- ➢ Forsberg K, Mansdorf SZ. *Quick Selection Guide to Chemical Protective Clothing,* 3rd ed. New York: Wiley, 1997.
- ➢ *Chemical Protective Clothing: Theory and Information* (volume 1): *Product and Performance Data* (volume 2). Fairfax, VA: American Industrial Hygiene Association, 1990.
- ➢ *American National Standard for Hand Protection Selection Criteria ANSI/ISEA 105-2000.* Arlington, VA: International Safety Equipment Association (ISEA), 2000.
- ➢ Computer data bases: Consult Mellstrom & Carlsson (1994) for a list of data bases.
- ➢ *NIOSH Pocket Guide to Chemical Hazards and Other Data Bases,* CD ROM, NIOSH Publication # 99-115. Cincinnati: NIOSH, April 1999 (available from the National Safety Council, [800] 621-7619).
- ➢ *Instant Gloves + CPC Data Base: Version 2.0.* Blacksburg, VA: Instant Reference Sources, Inc., 1999.
- ➢ Other sources: Consult Mellstrom et al (1994) for lists of other general texts on chemical protective clothing and the reference by Hamann & Kick (1994) for the selection of gloves for health care workers. Also see the discussion of contact urticaria/latex allergy above and of dermatologic reactions to gloves below.

Dermatologic reactions to gloves are classified as irritation from occlusion, friction, and maceration; allergy to glove materials and their chemical additives causing allergic contact dermatitis or allergy to certain natural rubber latex proteins causing contact urticaria; aggravation of preexisting skin diseases; and penetration of chemicals through gloves. Infrequent reactions to endotoxins and ethylene oxide, and to potentially depigmenting chemical constituents of gloves have been reported. Accurate diagnosis of any suspected adverse reactions to gloves is imperative before recommending alternatives to gloves. This is especially true of workers with contact urticaria to latex (latex allergy) who may still develop a severe reaction from gloves labeled as hypoallergenic. Because so-called hypoallergenic gloves may still contain allergenic latex proteins, synthetic gloves are necessary for these workers. See Table 4 in the Hamann & Kick (1994) and other chapters in the book *Protective Gloves of Occupational Use* (Mellstrom et al, 1994) for help in the selection of medical examination and sterile surgical gloves. *As this information may change, it is important to consult the glove manufacturer for the latest data.*

SAFETY

It is imperative that all safety gear be worn only when safely possible. Protective clothing, especially gloves, can be caught in moving machinery, resulting in serious injury.

Responsibility for Control

Top management, the safety department, the purchasing department, the medical department or company physician, the supervisors, and the workers all have specific responsibilities for the prevention of industrial skin diseases and the control of exposure to skin irritants.

To control or eliminate dermatitis in the workplace, management should first recognize the scope of the problem and then delegate authority for action to the proper employees. When it is necessary to have more than one department work on phases of dermatitis control or elimination, the activities of those departments should be coordinated. Periodic reports on the status of the dermatitis problem within the organization should be made to management by its delegated representatives.

The industrial hygienist (or people doing this type of work, such as the safety professional, safety committee members, the nurse, or the industrial hygienist) should gather information on dermatitis hazards of materials used in the plant and should disseminate this information among supervisors and other operating personnel. The industrial hygienist should make periodic surveys to check for exposure to skin irritants and should suggest means to correct any hazards found.

Case Examples of Control

The following examples of the use of controls to reduce or eliminate occupational dermatoses were taken from the 1978 *Report of the OSHA Advisory Committee on Cutaneous Hazards* and are still applicable today.

POWDERED EPOXY SPRAYING OPERATION

A manufacturer of household washing machines began using an epoxy material as a finished surface on its products. The epoxy material came in powdered form and was sprayed on the parts to be assembled, which were then baked in an oven to form an extremely hard surface. The spraying was done automatically, inside a booth. The parts passed through the booth hanging from an overhead conveyor. Overspray was exhausted out the bottom of the booth and into a barrel; some overspray remained on the inside walls of the booth. The only worker in the area during the spraying was an operator who sat inside an enclosed control booth and thus was not exposed to the epoxy powder.

On the midnight shift, however, when production was stopped, a cleanup crew entered the area to perform a number of duties:

- ➢ They used air hoses to blow out the overspray that had accumulated on the inside walls of the spray booth.
- ➢ They dumped barrels of exhausted overspray back into the supply system for reuse.
- ➢ They swept floors and other surfaces outside the booth to clean up some spray that had escaped the booth.

The powder was very fine and the slightest turbulence caused it to become airborne; consequently, a great concentration of epoxy dust was in the air. The cleanup crew was equipped with disposable respirators, hair covers, boots, and complete coveralls. Despite the personal protection, several members of the cleanup crew broke out in rashes after spraying had been performed for a few weeks.

The problem was solved, after an investigation, by changing the overspray exhaust system to return the overspray directly into the supply system, thus eliminating one major source of dust. Using a vacuum system rather than sweeping or air hoses eliminated the other sources of dust. No cases of dermatitis recurred.

MACHINING OPERATIONS

Exposure to cutting fluids in machining operations constitutes one of the major causes of industrial dermatitis. Controls that have virtually eliminated dermatitis have been instituted in many machining operations. For example, in one well-controlled plant that produces diesel engines, more than 2,000 workers on two shifts operating approximately 1,000 machines had not a single recordable case of occupational dermatitis in 1977, in contrast with some poorly controlled operations in which roughly 30 percent of the work force have skin problems. Control programs put into effect included the following:

- ➢ Careful identification, by generic name, of all ingredients in the cutting fluids used
- ➢ Programs to keep the coolant free of tramp oil, foreign particles, and dirt through the use of effective filters and redesign of the coolant flow system to eliminate eddies and backwash of coolant
- ➢ Daily programs to monitor coolant characteristics such as pH and bacteria count
- ➢ Daily programs such as hosing down to keep machinery clean
- ➢ Redesign of spray application to minimize coolant splash and spray
- ➢ Use of splash goggles and curtains
- ➢ Use of local exhaust systems and oil collectors to reduce airborne oil mist
- ➢ Use of abundant quantities of shop rags
- ➢ Provision of paid wash time to allow operators to keep clean

Experience shows that when the coolant is well-controlled and measures are taken to reduce the amount of coolant splashed on the worker, the rate of dermatitis is reduced.

For more information, see the NIOSH publication, *What You Need to Know About Occupational Exposure to Metalworking Fluids* (1998), which summarizes safety and health training, worksite analysis, hazard prevention and control and medical monitoring of exposed workers from the recently released NIOSH *Criteria for a Recommended Standard—Occupational Exposure to Metalworking Fluids.*

RUBBER MANUFACTURING

Improvements in rubber manufacturing operations have reduced problems with skin disease in the facilities where the improvements were made. These improvements have taken many forms:

- ➢ Methods of material handling have been improved to reduce the amount of skin contact with rubber and related chemicals.
- ➢ Known skin sensitizers have been replaced by less hazardous chemicals, such as the replacement of isopropylphenylparaphenyl-diamine (IPPD), used as an antioxidant in tires, with less toxic derivatives of paraphenylene diamine.
- ➢ Methods of mixing rubber chemicals have been improved to reduce exposure to a wide variety of known skin irritants and sensitizers; such improvements have included preblending chemicals, using exhaust-ventilated mixing booths, and automating the mixing process.

➢ In one plant, an air-conditioned isolation booth was installed for a worker who was strongly sensitized to an antiozonent.

For more information, see the NIOSH publication, *Rubber Products Manufacturing Industry* (1993), which summarizes health efects, exposures and research needs in the rubber industry.

CHEMICAL MANUFACTURING

A major producer of industrial chemicals has instituted a wide variety of controls that have resulted in a reduced rate of dermatitis. Their program includes the following controls:

➢ Extensive use of self-contained systems to handle chemicals to eliminate worker exposure to dermatitis-producing substances, designed with a goal of zero emissions
➢ Mechanization of material-handling systems to eliminate worker exposure to chemicals
➢ Emphasis on good housekeeping
➢ Use of wipe testing to check equipment surfaces for films of toxic materials
➢ Adoption of extensive employee education programs to inform employees of the risks of chemicals
➢ Implementation of programs of personal hygiene that, in the case of one particularly hazardous material, included three daily showers for the exposed employee
➢ For handling liquid chemicals, use of seal-less pumps and, where leaks cannot be permanently sealed, use of local exhaust systems; grouping of all pumps in one central area for better control; and scaling of floors around the pumps
➢ Preparation of educational materials to be supplied to purchasers of chemicals, including proper controls for the materials

SUMMARY

Occupational skin disorders are a significant cause of impairment and disability that in many cases are entirely preventable. Accurate diagnosis and a complete knowledge of the workplace are the keys to appropriate treatment and prevention. The industrial hygienist is a major player in this cooperative effort, along with the occupational physician, dermatologist, safety professional, and occupational health nurse.

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Chapter 4

The Ears

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This chapter covers the components of the external, middle, and inner ear, and how they function to produce hearing; the basic types of pathology that can affect the ears; how hearing is measured; the effects of noise on hearing and general health; and the effects of hearing loss on quality of life, and how this impairment is rated. The auditory mechanism enables us to hear sound conveyed from a source to our ears via gases, fluids or solids. The physics of sound generation and transmission is covered in detail in Chapter 9, Industrial Noise. This chapter provides an overview of our auditory system: the anatomy, physiology, and pathology of the human ear, evaluation of hearing, types of hearing loss, effects of noise exposure on hearing, and effects of hearing loss on communication.

ANATOMY AND PHYSIOLOGY

The organ of hearing is divided into three parts—the external, the middle and the inner ear. The entire system is shown in Figure 4–1.

External Ear

The external ear is composed of the auricle, or pinna, and the external auditory canal.

Auricle

The *auricle* (*pinna*) is the most visible part of the ear. It is a delicately folded cartilaginous structure with a few small muscles, covered by subcutaneous tissue and skin. The auricle collects sound waves from the air and funnels them into the ear canal to the tympanic membrane (eardrum).

External Auditory Canal

The *external auditory canal* (*meatus*) is a skin-lined pouch about 1.5 in. (3.8 cm) long, supported in its outer third by the cartilage of the auricle and in its inner two-thirds by the

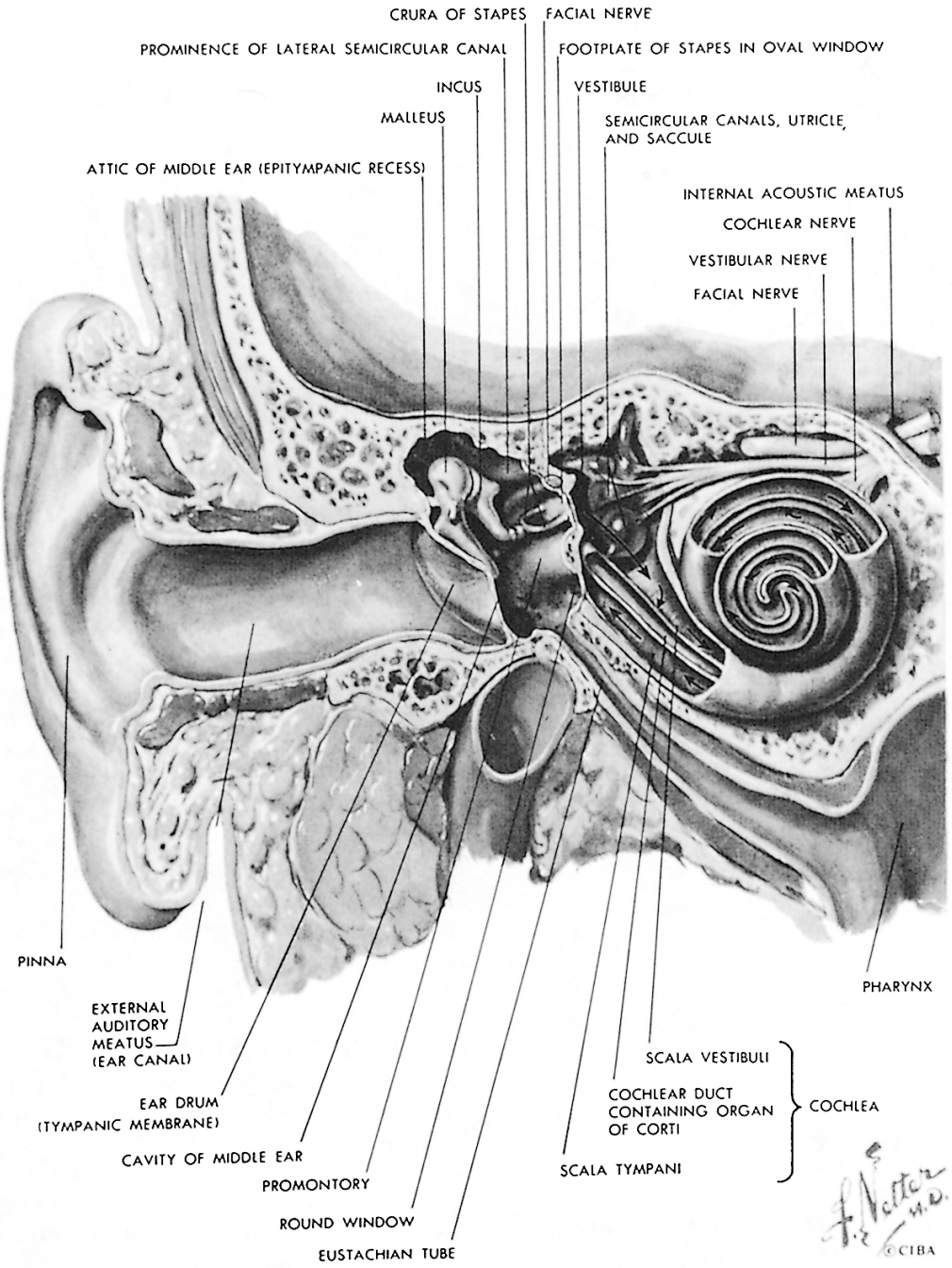

Figure 4–1. Illustration of the outer, middle, and inner ear. (Reprinted with permission from Netter FH, *Clinical Symposia.* CIBA Pharmaceuticals Co.)

bone of the skull. The cartilaginous meatus is curved and lies at an angle to the bony part, thus protecting the tympanic membrane and middle ear lying beyond it from direct trauma.

The small hairs, or *vibrissae,* and ceruminal glands, which secrete a waxy substance called cerumen, are located in the skin of the outer third of the ear canal. The hairs serve a protective function by filtering out particulate matter and other large pieces of debris. Cerumen, which is both sticky and bactericidal, prevents smaller particles from entering the ear canal and keeps the canal healthy and free of infection.

The function of the outer ear in the hearing process is relatively simple: The external portion of the ear collects sound waves from the air and funnels them into the ear canal, where they are transported to the eardrum. The collected sound waves cause the eardrum to move back and forth in a

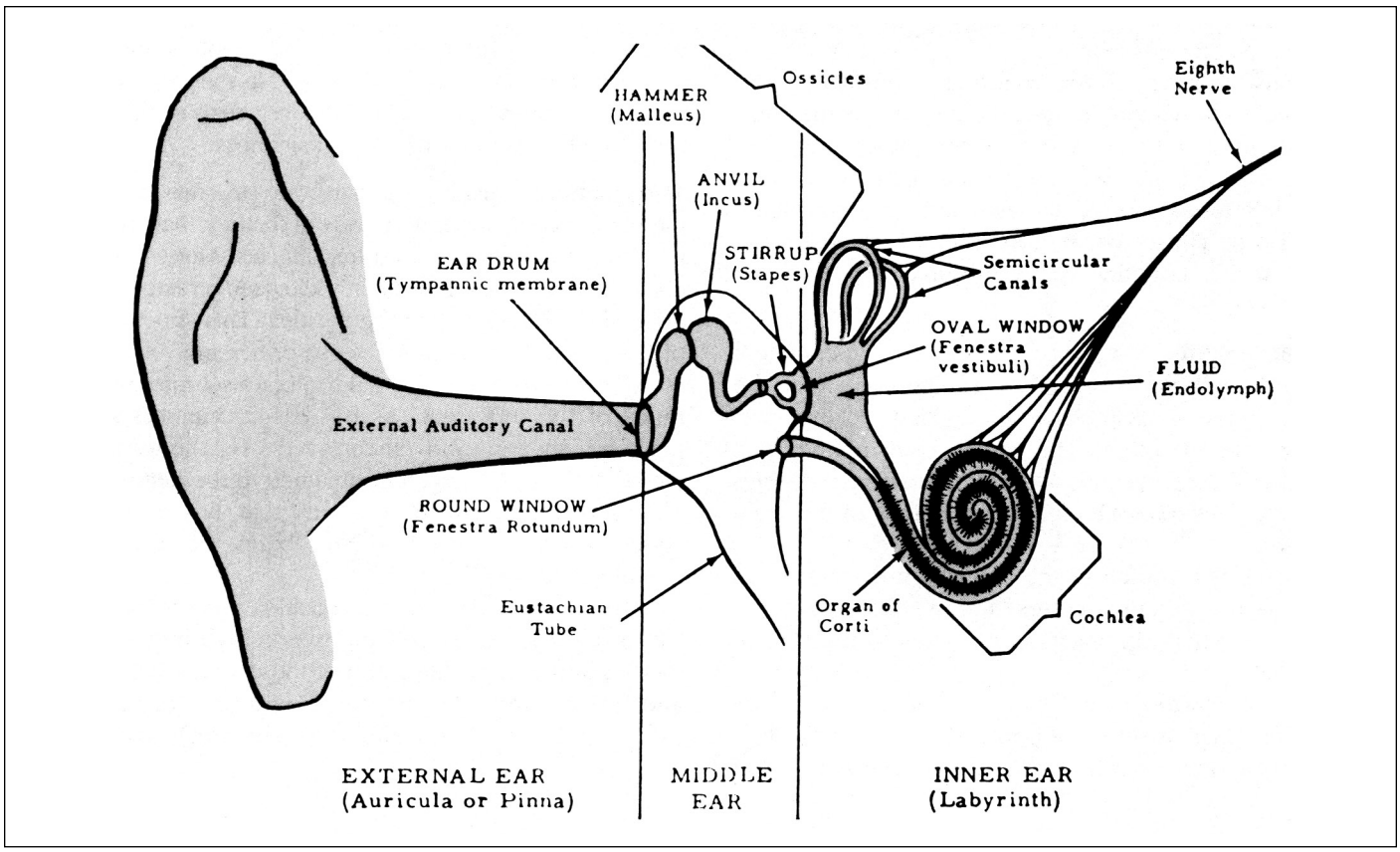

Figure 4–2. How the ear hears: Wave motions in the air set up sympathetic vibrations that are transmitted by the eardrum and the three bones in the middle ear to the fluid-filled chamber of the inner ear. In the process, the relatively large but feeble air-induced vibrations of the eardrum are converted to much smaller but more powerful mechanical vibrations by the three ossicles, and finally into fluid vibrations. The wave motion in the fluid is sensed by the nerves in the cochlea, which transmit neural messages to the brain. (Reprinted with permission from the American Foundrymen's Society.)

vibrating mechanical motion that is passed on to the bones of the middle ear (Figure 4–2).

Middle Ear

The middle ear is the space or cavity, about 1–2 mL in volume, between the eardrum and the bony wall of the inner ear (Figure 4–3). The middle ear is lined with mucous membrane essentially the same as that lining the mouth. The ossicles, which are the smallest bones in the body, are located within the middle ear cavity. The ossicles connect the eardrum to an opening in the wall of the inner ear called the oval window.

Picture the middle ear space as a cube:

- ➢ The eardrum forms the outer wall.
- ➢ The inner wall is the bony partition separating the inner ear from the middle ear. The round and oval windows fit into this wall and are the only two movable barriers between the middle and inner ear.
- ➢ The front wall opens into the eustachian tube.
- ➢ The back wall opens into the mastoid air cells.
- ➢ The roof separates the middle ear from the temporal lobe of the brain.
- ➢ The floor separates the middle ear from the jugular vein and the internal carotid artery, which lies high in the neck.

EUSTACHIAN TUBE

The *eustachian tube* serves to equalize pressure on either side of the tympanic membrane. An increase in pressure in the middle ear cavity, relative to atmospheric pressure, is usually compensated for passively by way of the eustachian tube. A decrease in pressure usually requires active ventilation by using muscles to open and close the eustachian tube (e.g., by yawning and swallowing).

EARDRUM

The eardrum is a membrane that separates the external ear canal from the middle ear. It consists of an inner layer of mucous membrane, a middle layer of fibrous tissue, and an outer layer of squamous epithelium. It is shaped like a spider web, with radial and circular fibers for structural support.

OSSICULAR CHAIN

The *ossicles,* which together are called the *ossicular chain,* are the *malleus, incus,* and *stapes.*

- ➢ The *malleus,* or hammer, is fastened to the eardrum by the handle. The head lies in the upper area of the middle ear cavity and is connected to the incus.
- ➢ The *incus,* also called the anvil, is the second ossicle and has a long projection that runs downward and joins the stapes.

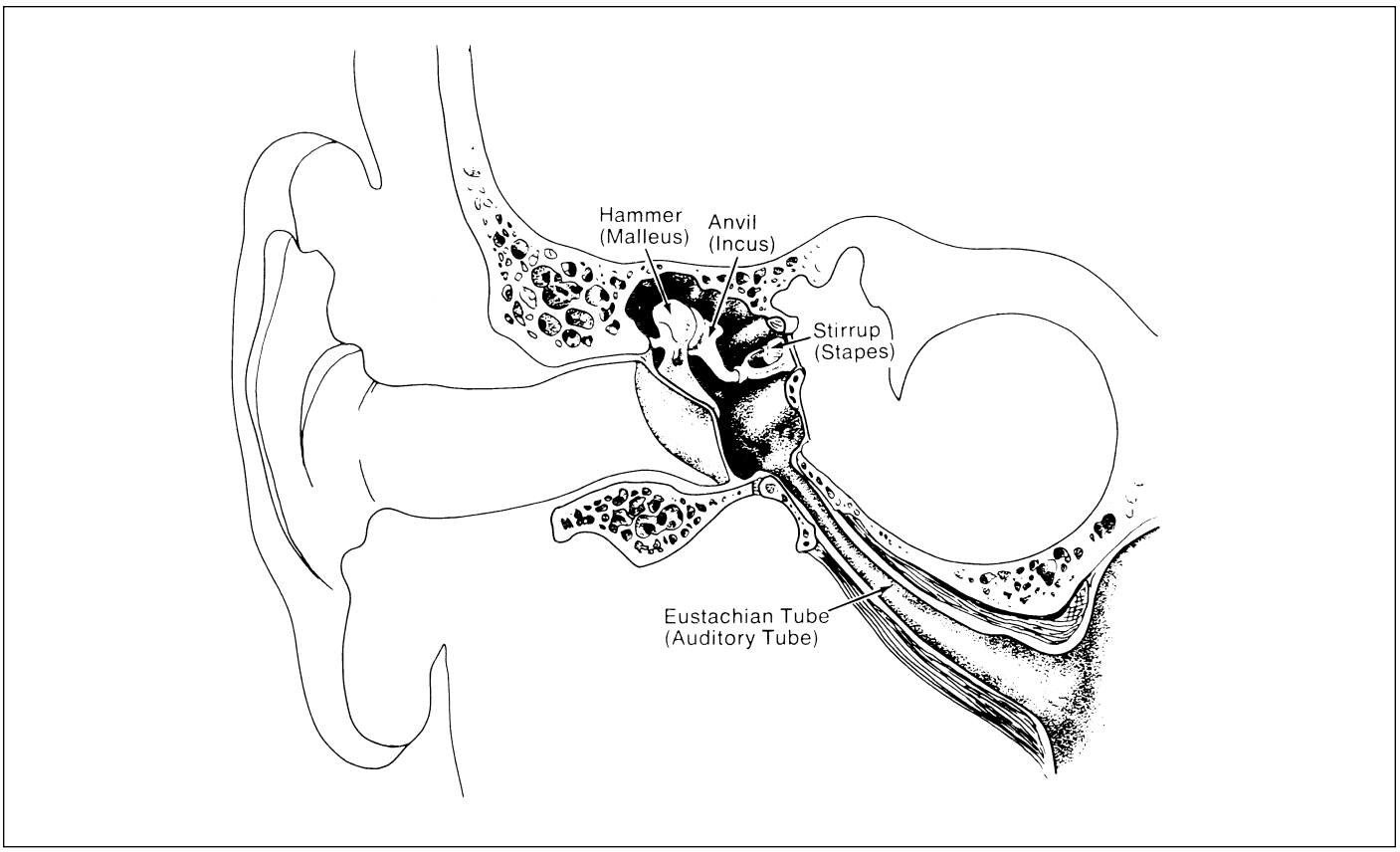

Figure 4–3. The middle ear is contained within the temporal bone and is made up of the eustachian tube, the middle ear space, and the mastoid air cell system. (Adapted from Figure 4–1.)

➢ The *stapes,* also called the stirrup, lies almost perpendicular to the long axis of the incus. The two branches of the stapes, anterior and posterior, end in the footplate that fits into the oval window.

The primary function of the middle ear in the hearing process is to transfer sound energy from the outer to the inner ear. As the eardrum vibrates, it transfers its motion to the attached malleus. Because the bones of the ossicular chain are connected to one another, the movements of the malleus are passed on to the incus, and finally to the stapes embedded in the oval window.

As the stapes moves back and forth in a rocking motion, it passes the vibrations on to the inner ear through the oval window (Figures 4–3 and 4–4). Covering the round window is a very thin membrane that moves out as the stapedal footplate in the oval window moves in. As the action is reversed and the footplate in the oval window is pulled out, the round window membrane moves inward. Thus, the mechanical motion of the eardrum is effectively transmitted through the middle ear and into the fluid of the inner ear.

AMPLIFICATION

The sound-conducting mechanism also amplifies sound by two main mechanisms. First, the large surface area of the base of the stapes (footplate) creates a hydraulic effect. The eardrum has about 25 times as much surface area as the oval window (Figure 4–5). All of the sound pressure collected on the eardrum is transmitted through the ossicular chain and is concentrated on the much smaller area of the oval window. This produces a significant increase in pressure. Second, the bones of the ossicular chain are arranged in such a way that they act as a series of amplifying levers. The long arms are nearest the eardrum and the shorter arms are near the oval window. The fulcrums are located where the individual bones meet. A small pressure on the long arm of the lever produces a much stronger pressure on the shorter arm. The magnification effect of the entire sound conducting mechanism is about 22 to 1.

Two tiny muscles attach to the ossicular chain: the stapedius to the neck of the stapes bone and the tensor tympani to the malleus. Loud sounds cause these muscles to contract, which stiffens and diminishes the movement of the ossicular chain, reducing the amount of sound energy transmitted to the inner ear.

MASTOID AIR CELL SYSTEM

On the back wall of the middle ear space is an opening that extends into the mastoid bone. This opening resembles a honeycomb of spaces filled with air.

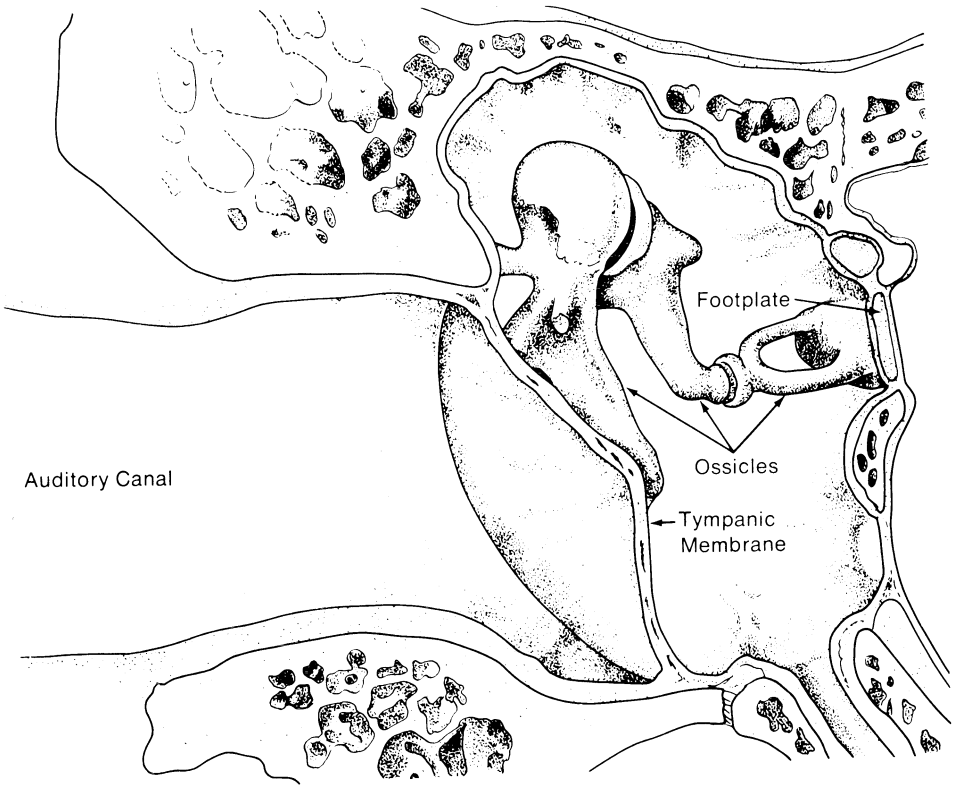

Figure 4–4. The ossicles, located in the middle ear cavity, link the eardrum to an opening in the wall of the inner ear (the oval window). (Adapted from Figure 4–1.)

Inner Ear

The inner ear contains the receptors for hearing and position sense. The major components of the inner ear include the vestibular receptive system and the cochlea, housed within the compact temporal bone (Figures 4–6 and 4–7). This bony labyrinth is filled with fluid called perilymph. The inner ear components are made up of a membranous labyrinth structure, which is suspended in the perilymph. Within the membranous labyrinth are the sensory organs for hearing (the cochlea) and position (the vestibular system), bathed in endolymph fluid.

COCHLEA

The *cochlea* is a tubular snail-shaped structure lined with the basilar membrane, which contains thousands of feathery *hair cells* tuned to vibrate to different sound frequencies. Nerve endings are contained in a complex, slightly elevated structure over the floor of the tube forming the cochlea. This structure, the *organ of Corti,* is the essential receptor end organ for hearing. It is a very complicated structure, consisting of a supporting framework on which the hair cells rest.

Vibrations of the stapedial footplate set into motion the fluids of the inner ear. As the basilar membrane is displaced, a shearing movement occurs on the tectorial surface that drags the hair cells attached to the nerve endings. This sets up electrical impulses that are appropriately coded and transmitted to the brain via the auditory (or cochlear) nerve (Figure 4–8). The frequency or pitch of the sound determines which part of the cochlea responds (high frequencies stimulate the base of the cochlea near the oval and round windows, whereas the nerve endings that respond to low frequencies are located at the small end of the cochlea).

VESTIBULAR SYSTEM

Our sense of balance is dependent not on hearing, but on organs of equilibrium. Near the cochlea are three semicircular canals lying in planes perpendicular to each other (Figure 4–9). The canals contain endolymph fluid that responds to movement of the head. Additional positional information is provided by receptors located in the vestibule. The vestibular branch of the auditory nerve (combined, called the eighth cranial nerve) transmits these impulses to the cerebral cortex and we recognize the position of our head in space as it relates to the pull of gravity.

PATHOLOGY

A number of disorders can affect the components of the auditory system. In this section, some of these conditions and their relevance to the occupational setting will be

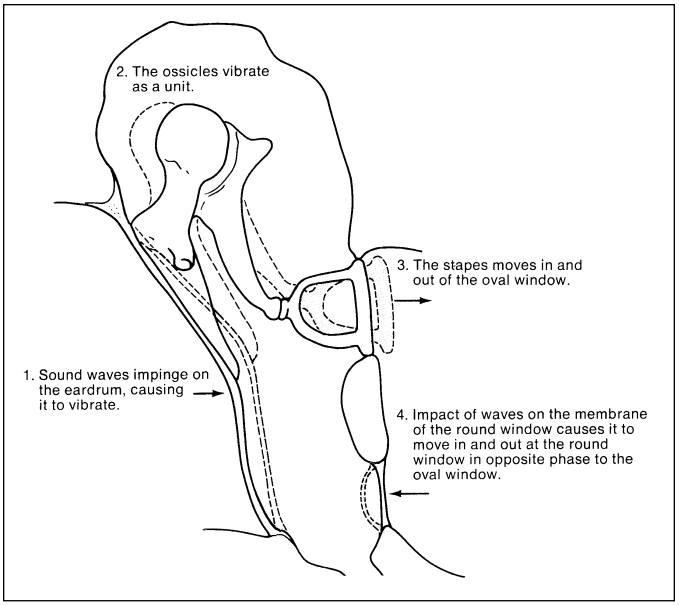

Figure 4–5. The eardrum has about 25 times as much surface area as the oval window. All of the sound energy collected on the eardrum is transmitted through the ossicular chain to the smaller area of the oval window.

presented, along with a review of hearing assessment and the effects of noise.

Pathology of the External Ear

This section begins with a look at the pathology of the external ear—specifically the pinna and auditory canal, the eardrum, and the eustachian tube.

PINNA AND AUDITORY CANAL

Because of its prominence and its thin, tight skin, the *pinna* is especially subject to sunburn and frostbite. Thus, it must be protected from the elements. Injured cartilage is replaced by fibrous tissue and repeated injuries result in the cauliflower-shaped ear seen on many boxers. Disorders of the auricle include congenital malformations (in which the cartilage is misshapen) and protruding or lop ears, both of which may be surgically corrected. Dermatitis and infection are common in this area, and can arise locally or spread from other body sites. Deformation or inflammation of the pinna can affect a worker's comfort in using headwear and muff-type hearing protection.

The *ear canal* is prone to infection (otitis externa) because of its high skin temperature and humidity. These bacterial or fungal infections occur more readily under circumstances of heavy perspiration or head immersion (hence the name, "swimmer's ear"). Skin disorders (dermatitis) are also common ear canal problems, and can either occur locally or spread from the scalp and other skin areas.

Foreign objects accidentally lodged in the ear canal can be dangerous and should be removed only by a physician. A live

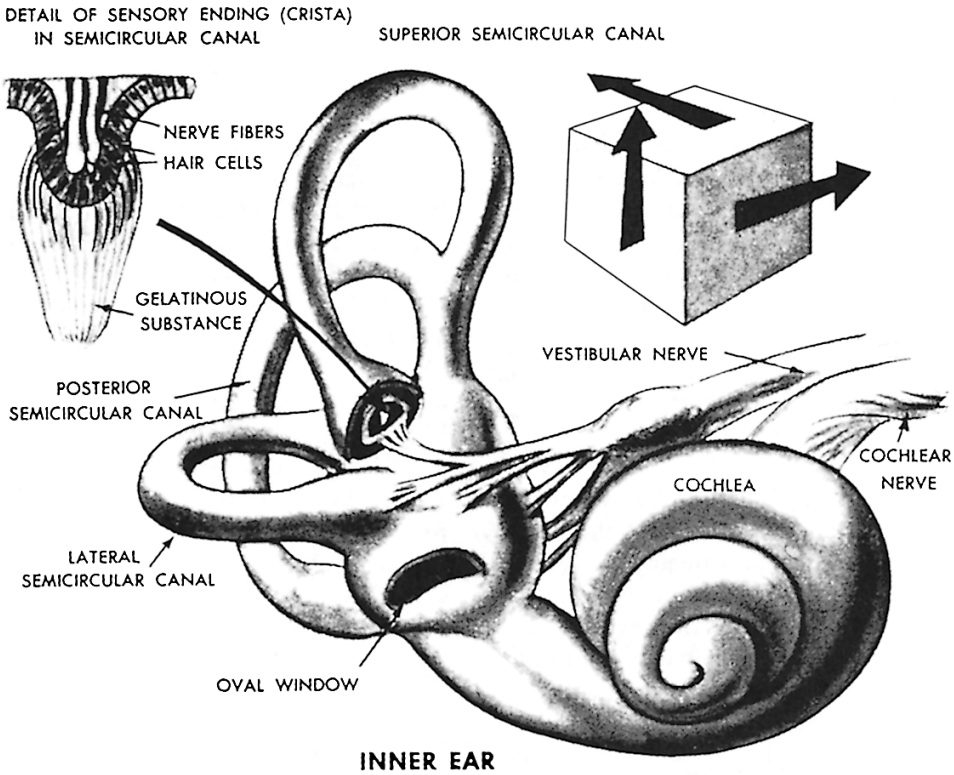

Figure 4–6. The three subdividsions of the inner ear: the cochlea, the vestibule, and the semicircular canals. (Reprinted with permission from the American Medical Association, *The Wonderful Human Machine.* Chicago: AMA, 1971.)

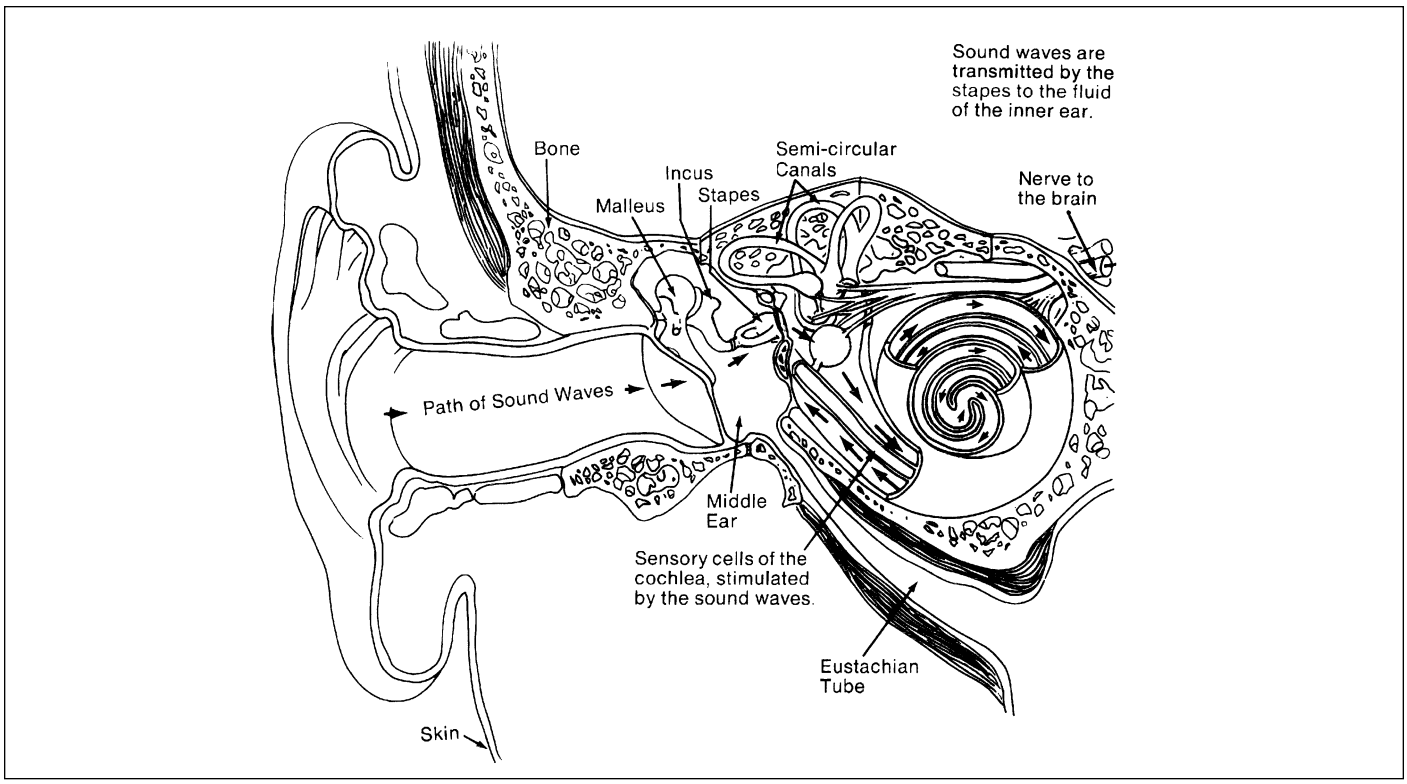

Figure 4–7. The major components of the inner ear, including the vestibular system and the cochlea. (Adapted from Figure 4–1.)

insect in the ear canal can be especially annoying or painful. If this happens, drop light mineral oil into the canal to suffocate and quiet the insect until it can be removed. Normally, the ear canals are self-cleaning but occasionally this mechanism fails, resulting in wax impaction. The use of cotton-tipped swabs for cleaning tends to pack wax into the ear canal. Also, swabbing stimulates excess production of wax.

An abnormal narrowing of the ear canal is called stenosis and may be caused by congenital malformation, bony growth (exostosis) or infection. Tumors are rare in this area. Abnormalities in ear canal anatomy, or canal infection/inflammation, can cause difficulties in using earplugs or other insert hearing protective devices. It is not common for ear canal problems to affect hearing; the canal must be almost totally occluded (blocked) before attenuation of sound occurs.

EARDRUM

Infections localized to the eardrum are rare; when they do occur, they are caused by viruses such as the varicella zoster virus (shingles). However, the eardrum is often included in infections of the external auditory canal or the middle ear.

Perforation or rupture of the tympanic membrane can be caused by infection, direct injury (e.g., from penetrating object) or sudden pressure changes (barotrauma). Examples of the latter would be a blow to the side of the head, or large pressure changes associated with air flight, underwater diving, or explosions. Most perforations heal spontaneously and do not require surgical repair, except for those caused by hot substances such as welding splatter.

EUSTACHIAN TUBE

In the presence of swelling, adhesions, or masses the eustachian tubes can become obstructed. This is a common consequence of allergic and infectious conditions that affect the nose and throat. Failure of the eustachian tube to ventilate creates a vacuum in the middle ear space, which in turn causes one of two pathological events to occur: It pulls fluid into the middle ear, resulting in a condition called nonsuppurative (serous) otitis media, or it pulls the eardrum inward (retraction). Either one of these events can interfere with mobility of the tympanic membrane, causing hearing loss. Eventually any serous fluid present can thicken and create persistent hearing problems.

The opposite condition, which is uncommon, is a patent eustachian tube in which the tube constantly remains open. This condition results in the annoying symptom of hearing one's own voice and breath sounds (autophonia) in the involved ear.

Pathology of the Middle Ear

The middle ear space is prone to infectious diseases, especially in childhood. These are predominantly bacterial in origin and called suppurative otitis media. Because the middle ear space connects with the mastoid air cell system, infection can easily spread to this area (mastoiditis). Before the days of

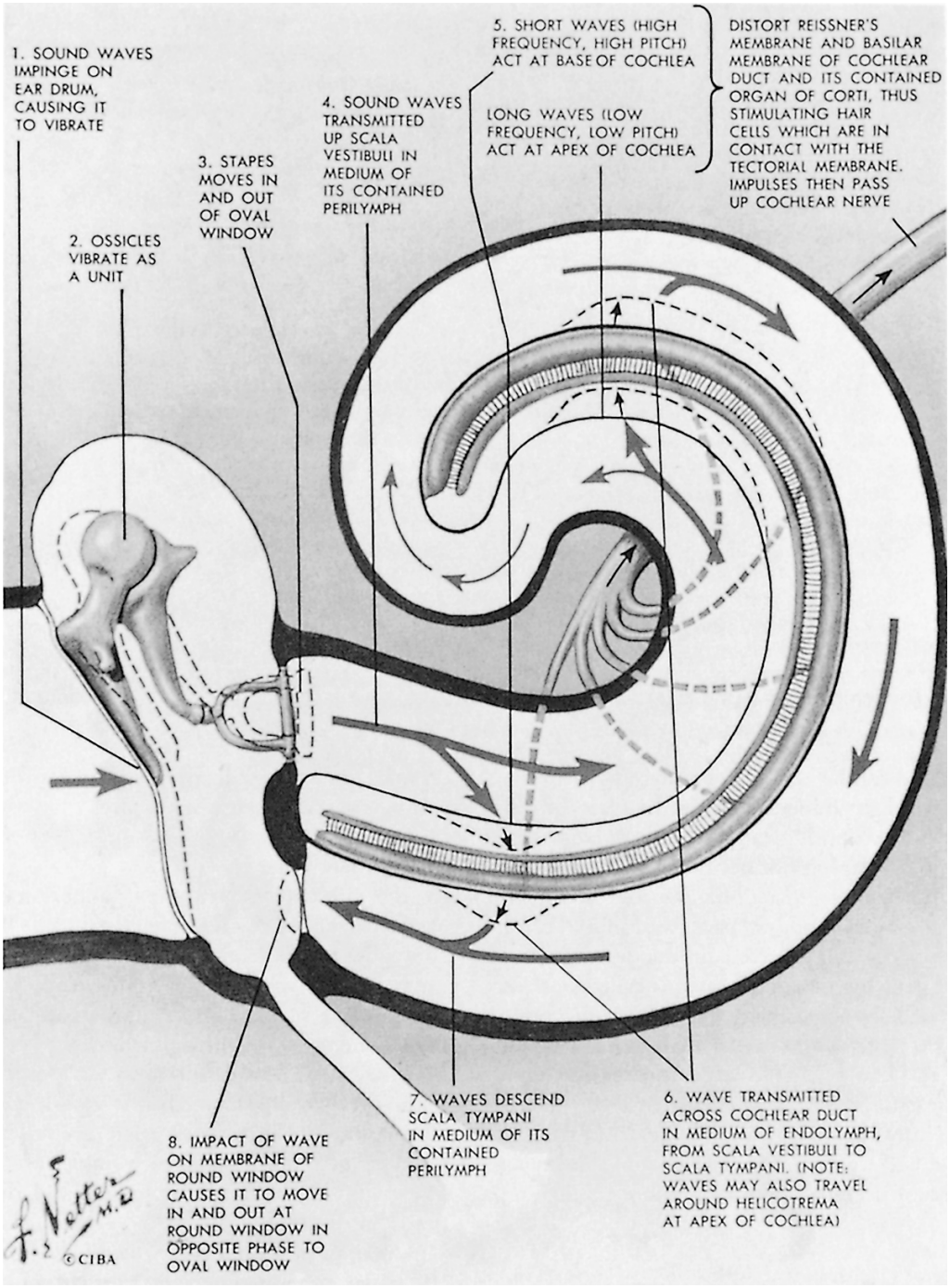

Figure 4–8. The mechanism for transmission of sound vibrations from the eardrum through the cochlea. (Reprinted with permission from Netter FH, *Clinical Symposia*. CIBA Pharmaceutical Co.)

antibiotics, these were serious, often life-threatening problems because the infection could spread to the brain or major vessels surrounding the ear. Though less likely to occur today, these dangers still exist.

Disease of the middle ear *ossicles* can impair hearing in two ways:

- ➢ fixation (the bony chain cannot vibrate or vibrates inefficiently) and
- ➢ interruption (a gap in the chain)

Fixation can result from developmental errors, adhesions, or scars from old middle ear infections or bone diseases that affect this area. Otosclerosis is a prime example of fixation. It usually

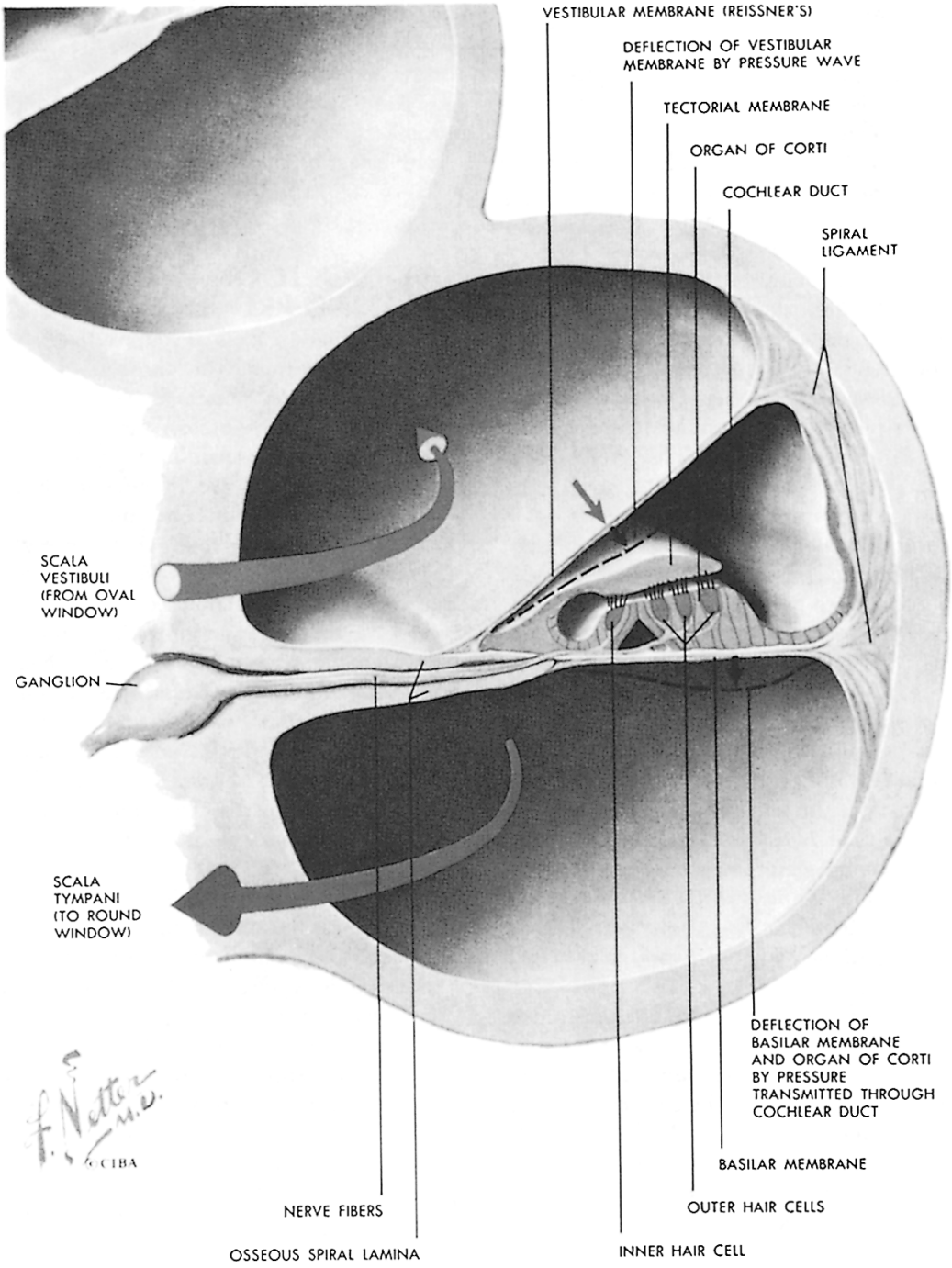

Figure 4–9. This schematic diagram depicts the transmission of sound across the cochlear duct, stimulating the hair cells. (Reprinted with permission from Netter FH, *Clinical Symposia*. CIBA Pharmaceutical Co.)

begins in early adult life. Interruptions are usually caused by middle ear infections, cholesteatomas, or head injuries.

Conductive hearing loss is hearing loss that arises from conditions affecting the outer or middle ear. This is because sound waves cannot be conducted effectively to the cochlear sensory organ via the normal pathways. Some amount of sound energy can still be transmitted to the inner ear by direct transmission through the cranial bone; although the loudness of sounds is diminished, clarity of sound is preserved because the cochlea retains its phenomenal sensitivity to a wide range of sound characteristics.

Pathology of the Inner Ear

A variety of ailments can affect the delicate cochlea, semicircular canals and eighth cranial nerve. For example, damage to these components can result from congenital/developmental

defects, systemic diseases (multiple sclerosis, diabetes), infection (mumps or chronic otitis media), exposure to noise or certain toxins (including medications, such as some antibiotics or diuretics), circulatory problems (stroke) and trauma (concussion or skull fracture). In the workplace, exposure to excessive vibration, heavy metals, organic solvents and carbon monoxide may contribute significantly to the hearing loss induced by chronic ambient noise or other medical problems.

A steady loss of hearing acuity often occurs as we grow older (presbycusis). The normal young ear can hear tones within a range of 20 Hz (the lowest bass note of a piano) up to high-pitched sounds of 20,000 Hz. People in their 60s are lucky to hear normal level sounds at 12,000 Hz. This hearing loss is greater for high-frequency sounds and is considered normal because it happens to practically everybody as the years roll on.

Disorders affecting the vestibular system can cause loss of balance, vertigo, and nausea or vomiting. Examples of these disorders include *viral labyrinthitis* and *Meniere's disease*. Meniere's disease affects both parts of the inner ear (hearing and balance) and its cause is unknown. It is characterized by episodic dizziness, often severe, and associated with nausea and vomiting, fluctuating hearing loss that is generally progressive, ringing or hissing noise (tinnitus), and a peculiar sensation of fullness in the involved ear.

Another important condition that can affect the eighth cranial nerve is acoustic neuroma. This tumor occurs most commonly in middle-aged persons. Although not malignant, it can cause disabling symptoms of both hearing loss and vestibular dysfunction. Workers with vertigo or equilibrium problems may not be medically fit for safety-sensitive tasks such as operating motor vehicles or working at heights (ladders, etc.).

Sensorineural hearing loss is the hearing difficulty caused by inner ear damage. (*Sensori-* refers to the sense organ in the inner ear, and *-neural* refers to the nerve fibers). Sensorineural can involve impairment of the cochlea, the auditory nerve, or both. Unlike conductive hearing loss, the hearing deficit cannot be overcome by sound transmission through the bone. Often both the perception of loudness and clarity of sound are impaired.

Tinnitus

Tinnitus is a symptom, not a disease. It is a perception of sound arising in the head. It may be heard only by the affected person (subjective tinnitus) or it may be audible to the examiner also (objective tinnitus). Objective tinnitus is usually a symptom not of disease of the ear but of a tumor or vascular malformation. All cases should be evaluated by a qualified physician.

Subjective tinnitus is usually perceived as a ringing or hiss. Occasionally, no explanation can be found, but most cases are secondary to high-frequency hearing loss. Some cases can be caused by wax, perforation of the drum, or fluid in the middle ear. Drugs or stimulants such as caffeine, aspirin, or alcohol can also cause the symptom by disturbing the inner ear.

Tinnitus can lead to psychological stress and be disabling. Maskers that match the frequency of the tinnitus, combined with a hearing aid, can be helpful. Patient education is essential to successful treatment.

A QUICK LOOK AT THE HEARING PROCESS

The external ear collects sound waves and funnels them to the tympanic membrane through the ear canal. The tympanic membrane vibrates in response to the sound waves that strike it. This vibratory movement, in turn, is transmitted to the ossicular chain in the middle ear. The vibration of the ossicles creates waves in the inner ear fluid that stimulate microscopic hair cells. The stimulation of these hair cells generates nerve impulses which pass along the auditory nerve to the brain for interpretation.

The outer and middle sections of the ear conduct sound energy to the deeper structures. Therefore, the outer and middle ear sections act together as the conductive hearing mechanism. In contrast, the deeper structures, including the inner ear and the auditory nerve, are referred to as the sensorineural mechanism. Although nature has surrounded the delicate ear mechanism with hard, protective bone, any portion of the ear can become impaired. The part of the hearing mechanism affected and the extent of damage has a direct bearing on the type of hearing loss that results. The words *conductive* and *sensorineural* describe two major types of hearing impairment.

As long as the hearing mechanism functions normally, the ear can detect sounds of minute intensity while tolerating sounds of great intensity. The loudest sound the normal ear can tolerate is more than 100 million (10^8) times more powerful than the faintest sound the ear can detect (see Figure 4–10). Furthermore, a young listener with normal hearing can detect sounds across a wide frequency range, from very low-pitched sounds of 20 Hz to very high-pitched sounds of 20,000 Hz.

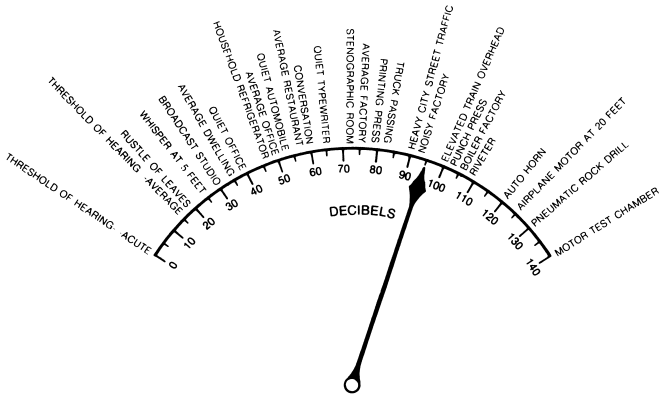

Figure 4–10. Typical sound levels associated with various activities.

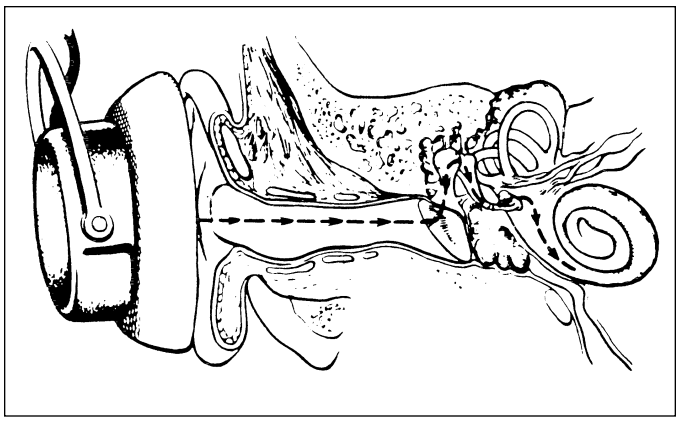

Figure 4–11. An air-conduction earphone is depicted; note that the earphone is placed directly over the external ear canal and the sound waves are conducted (by air) to the eardrum and through the middle ear to the inner ear.

HEARING MEASUREMENT

The measurement of hearing is done using an audiometer. This is described in the next section.

Audiometer

An audiometer is a frequency-controlled audio-signal generator. It produces a pure tone signal, the frequency and intensity of which are varied for use in hearing measurement. Audiometry is used to determine hearing thresholds for both pure tone and speech, by air conduction and bone conduction.

The audiometer was developed to provide an electronic pure-tone sound similar to that of the tuning fork. With the audiometer, however, intensities can be controlled much more accurately and, therefore, the results can be more carefully quantified. The equipment is calibrated according to American National Standard Institute (ANSI) standards *Specification for Audiometers* (ANSI S 3.6 1996) and *Reference Zero for the Calibration of Pure Tone Bone-Conduction Audiometers* (ANSI S3.43-1992).

AIR CONDUCTION TESTING

When testing hearing by air conduction, headphones are placed over the ears of the test subject. A pure tone signal from the audiometer is presented through the headphones and travels through the ear canal, the middle ear and into the inner ear, thus allowing evaluation of the entire hearing mechanism, both conductive and sensorineural (Figure 4–11).

BONE CONDUCTION TESTING

Bone conduction audiometry evaluates only the sensorineural hearing mechanism. A bone vibrator is placed on the mastoid bone behind the outer ear. This sends vibrations directly through the skull bones to the cochlea in the inner ear, bypassing the conductive pathway of the outer and middle ear (Figure 4–12). Bone conduction testing is considered a diagnostic test and is not performed as part of routine industrial hearing assessments.

Audiogram

Audiometric results are recorded on a standard chart called an audiogram (Figure 4–13). It is a frequency-by-intensity graph on which a person's hearing threshold for pure tones is plotted.

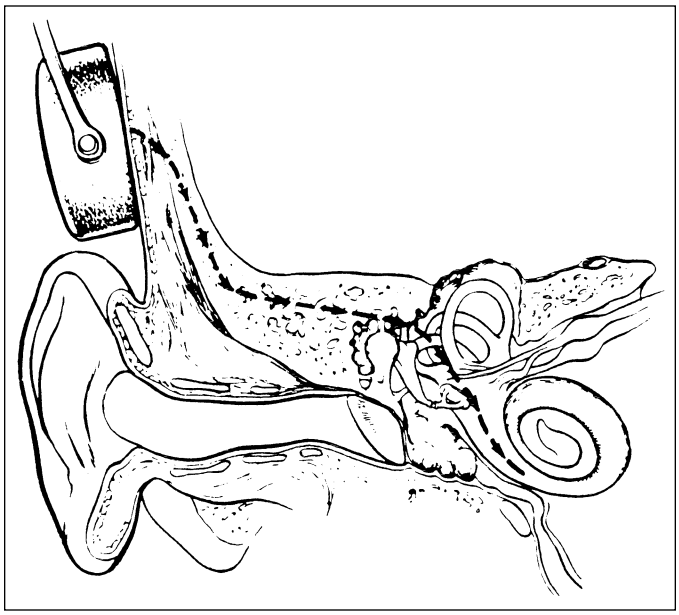

Figure 4–12. Sound can be transmitted directly to the inner ear through the bones of the skull using a bone-conduction vibrator placed on the mastoid bone behind the outer ear. The broken line (with arrows) shows the path taken by the sound waves through the bony areas of the head to the inner ear.

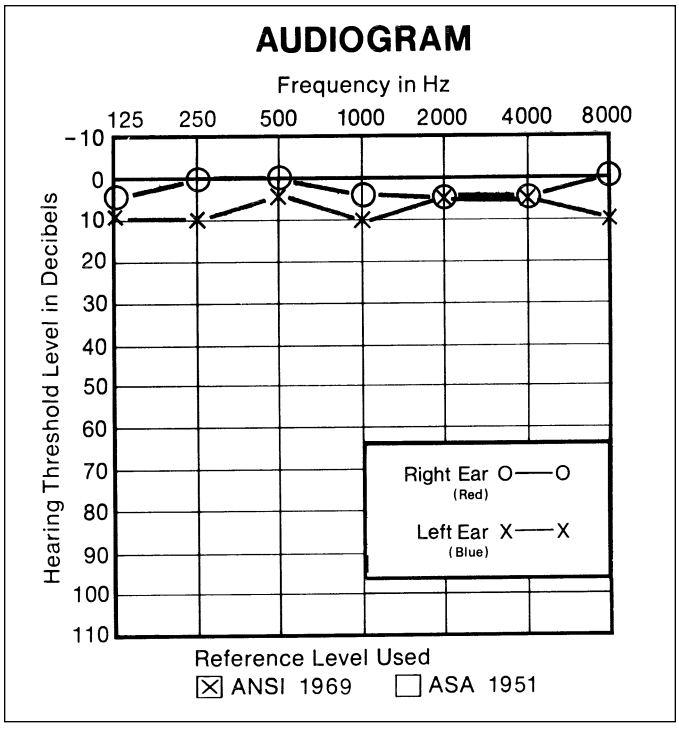

Figure 4–13. A typical manual audiogram showing hearing thresholds within the normal range.

The numbers across the top represent the frequency, or pitch, of the tones from the lowest frequency (125 Hz) to the highest frequency (8,000 Hz). For example, a 250-Hz tone corresponds to middle C on the piano while a 4,000-Hz tone sounds much like a piccolo hitting a high note. The vertical column of numbers on the left side of the graph represents intensity, or loudness, in decibels (dB). The smaller the number, the lower the dB level, the softer the sound (e.g., 10 dB) and conversely, the larger the number, the higher the dB level, the louder the sound (e.g., 100 dB).

Threshold of hearing is the very softest level at which a person is able to hear. When a threshold, measured in dB, is determined through audiometry at any given frequency, the result is plotted on the graph. Audiometric symbols used for recording results are specified by ANSI standards. Pure tone, air conduction thresholds are plotted with an "0" for the right ear and with an "X" for the left ear. A threshold of 0 dB indicates that there is no difference between the hearing sensitivity of a test subject compared with a normal standard.

The American Academy of Ophthalmology and Otolaryngology has recommended that audiograms be drawn to a scale like the illustration shown in Figure 4–13. For every 20-dB interval measured along one side and for one octave measured across the top (250–500 Hz, for example), there is a perfect square. The reason for a standardized scale is that the apparent hearing loss can be altered a good deal by changing the dimensions of an audiogram. If the proportions of the audiogram are different from standard dimensions, a person's hearing loss may look quite different than if it were plotted on the standard audiogram format. Customarily, audiograms are scaled in 10-dB steps. Of course, if a person has a threshold of 55 dB, it is plotted on the appropriate frequency line at the halfway point between 50 and 60 dB.

Hearing losses plotted on a standard chart produce a profile of a person's hearing. A trained person can review an audiogram to determine the type and degree of hearing loss and can estimate the difficulty in communication this loss will cause.

EFFECTS OF NOISE EXPOSURE

Exposure to noise can cause temporary or permanent damage to the auditory system. In addition, noise appears to be harmful to our general health, in ways that are not yet fully appreciated.

Noise-Induced Hearing Loss

Noise (defined as unwanted sound) is a pervasive, insidious cause of hearing loss. It causes no particular pain unless it is as loud as a rifle blast. The ears have considerable comeback power from brief exposure to *intense* noise and ordinarily recover within 14 hours or so (this is called a temporary threshold shift [TTS], typically most prominent at 4,000 Hz). However, prolonged exposure to intense noise gradually damages the cochlear hair cells of the inner ear (see Figure 4–14), resulting in a permanent threshold shift (PTS) across multiple frequencies (see Figure 4–15).

What are the factors that determine the duration and severity of noise-induced hearing loss?

- ➢ *Sound level*—Sound levels must exceed 60–80 dB before the typical person will experience a temporary decrease in hearing sensitivity. NIOSH estimates that eight percent of individuals exposed at the NIOSH Recommended Exposure Limit (85 dB, A-weighted, averaged over eight hours/day for 40 years) will develop noise-induced hearing loss.
- ➢ *Frequency distribution of sound*—Sounds having most of their energy in the speech frequencies (500 Hz–2,000

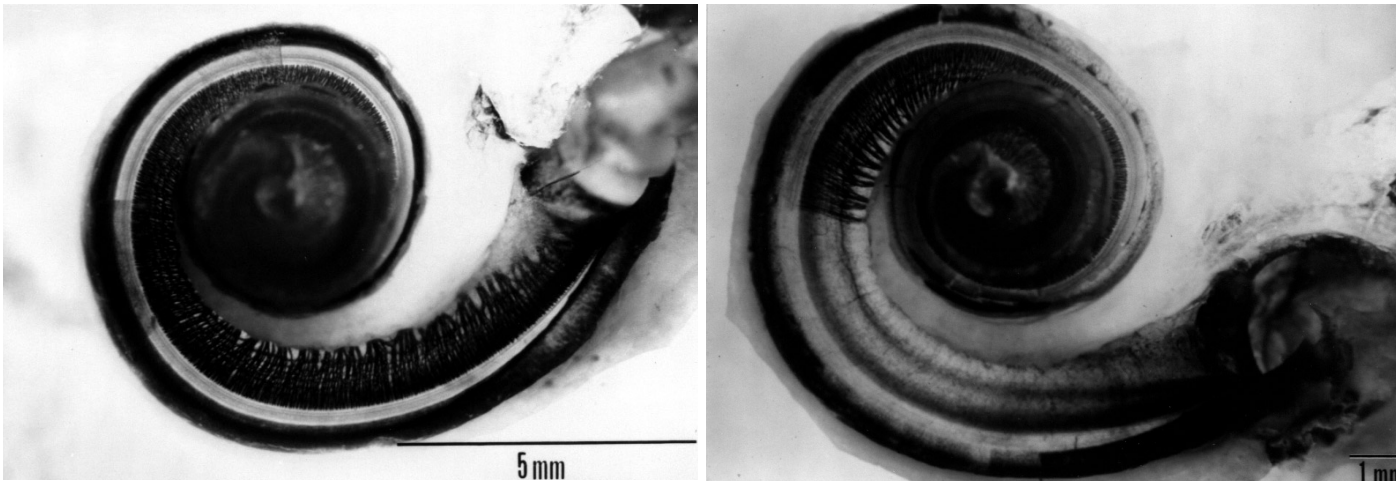

Figure 4–14. Enlarged views of human cochlear specimens. Compare the normal cochlea on the left with that of a 50–year-old patient exposed to noise during factory work and recreational hunting activities. Note the nearly complete loss of the organ of Corti and nerve fibers throughout the base of the cochlea, consistent with his irreversible high frequency hearing loss. (Courtesy of J. E. Hawkins, DSc and L.G. Johnsson, Kresge Hearing Research Institute.)

Hz) are more potent in causing a threshold shift than are lower frequency sounds.

- ➢ *Duration of sound*—For a given sound level, longer duration exposure increases the risk of hearing effects.
- ➢ *Temporal distribution of sound exposure*—The shorter and less frequent the quiet periods between periods of sound, the greater the hazard.
- ➢ *Type of sound energy* (continuous, intermittent, impulse, or impact)—The tolerance to peak sound pressure is greatly reduced by sudden changes in the sound energy level.
- ➢ *Individual differences in tolerance of sound*—Sensitivity to noise-related hearing loss varies widely among individuals, but there are no reliable predictors to identify those at increased risk.

Millions of workers in the United States are exposed to significant levels of noise on the job. For this reason OSHA has required formal hearing conservation programs for most employees exposed above the Action Level (currently 85 dBA averaged over an eight-hour workday) since the mid-1970s (see Chapter 9, Industrial Noise). Occupational health and safety professionals should also be aware that recreational (nonoccupational) noise exposure from music, firearms, and vehicles such as snowmobiles and motorcycles is fairly ubiquitous, and incorporate this information into worker risk assessment and education programs.

Nonauditory Effects of Noise

Research on other effects of noise indicates that it may cause interference with communication, altered performance, annoyance, and physiological responses such as elevated blood pressure and sleep disturbances. Definitive studies have yet to be done on most of these issues. Certainly, levels of background noise above 80 dBA reduce the intelligibility of speech to workers with normal hearing. Furthermore, repeated shouting to overcome noise has been observed to lead to chronic laryngitis and even traumatic vocal cord polyps. However, the stress effects of noise (decreased attention, accidents, hypertension, and sleep problems) are not consistently correlated with noise level.

Noise exposure does seem to have deleterious health effects during pregnancy. Women exposed to high levels of noise are at increased risk of shortened gestation and delivery of preterm or low birthweight infants. Fetal exposure to noise may result in birth defects and permanent hearing deficits, although human and animal studies have not demonstrated this conclusively.

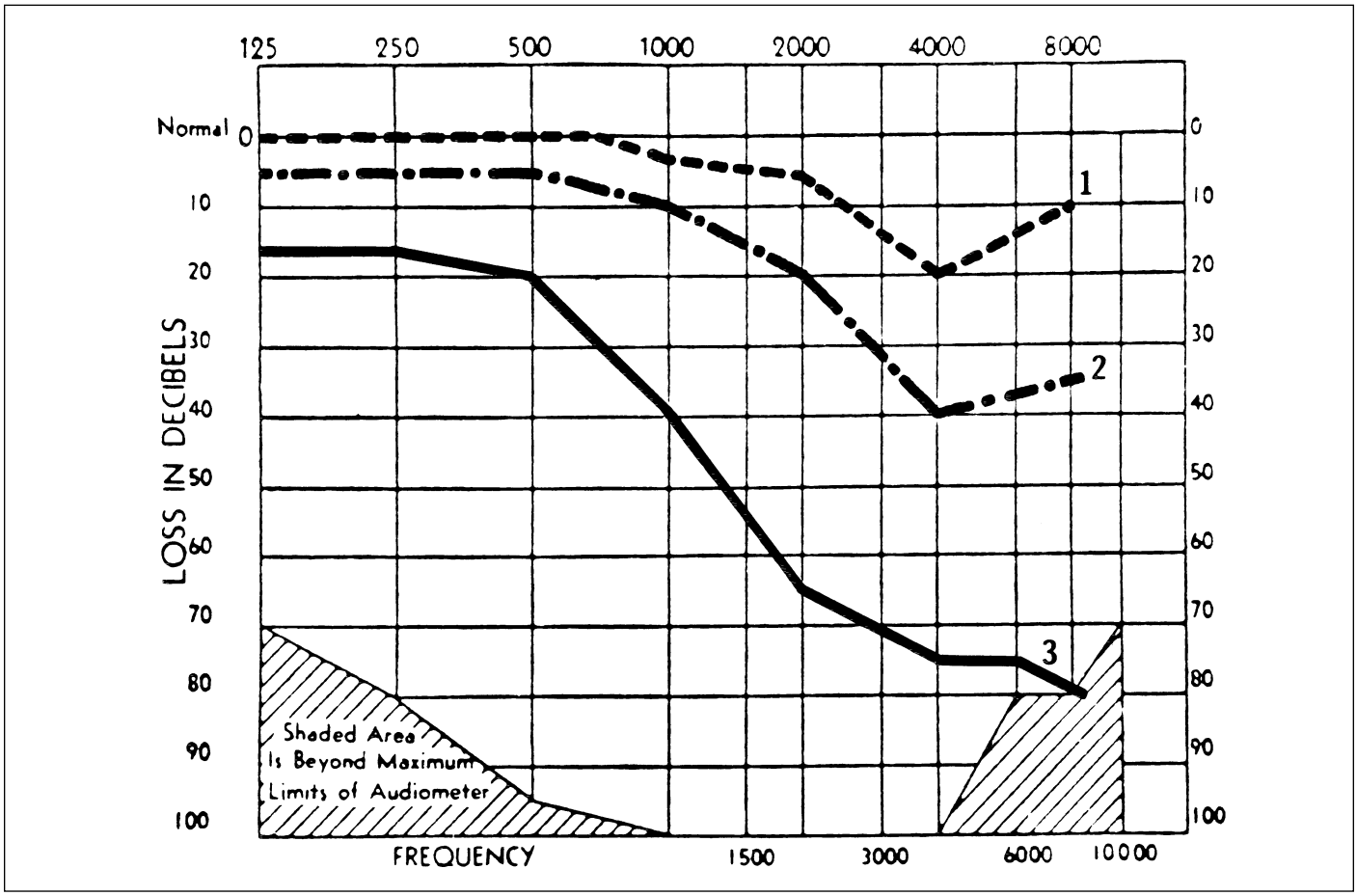

Figure 4–15. Sensorineural hearing losses of the kind produced by noise or other causes. Curve 1 = early; curve 2 = intermediate; curve 3 = advanced. (As shown, curve 3 might include some involvement of presbycusis.)

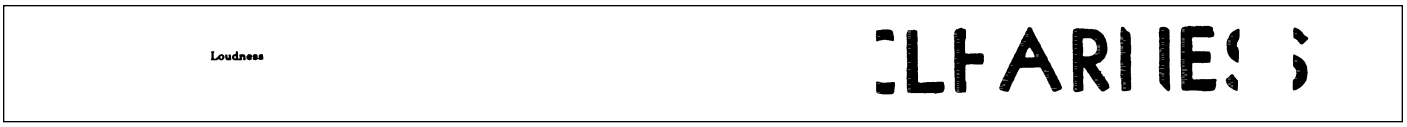

Figure 4–16. Both sides of this illustration visually represent two important dimensions of normal hearing: the ability to hear sounds as loudly as they really are and the ability to hear sounds with complete clarity. Leff: It is almost impossible to read the word Loudness; this is comparable to not being able to hear faint sounds. Moving the figure closer makes it easier to read, just as increasing volume makes sounds easier to hear. Right: No matter how closely the illustration is held, it is difficult to interpret. The word is not clear because some important parts of the letters are missing. This shows, by analogy, hearing difficulty caused by a loss in the ability to distinguish between various sounds (the word is CLEARNESS).

COMMUNICATION

Quality of life can be drastically affected for individuals whose hearing has been impaired by exposure to noise. Verbal communication, our primary connection to other human beings, often becomes a source of frustration for the person with the hearing loss as well as for family and friends. Typically, this type of hearing loss produces inconsistent auditory behavior. That is, in certain situations there may be no problem hearing whereas in others there can be considerable difficulty.

To better understand why this occurs, we will discuss two important characteristics of hearing: loudness, the ability to hear sounds as loud as they actually are, and clarity, the ability to hear sounds clearly and distinctly.

Loudness

If Figure 4–16 is held at arm's length, the printing on the left side is obvious but almost impossible to read. A close look confirms that it is indeed a word; an even closer look reveals that the word is *Loudness*. This example is analogous to the concept of loudness as it relates to hearing and hearing loss. For some types of hearing loss, sounds only need to be made louder to hear, just as the word *Loudness* needed to be made bigger to see.

Clarity

If Figure 4–16 is held at arm's length, there is no difficulty in seeing everything on the right side. But can the word be read? If not, the reason is that too much of the word is missing, even though it is large enough. Regardless of how closely you look, it is difficult to read because some of the important parts are missing. This illustrates the problem of loss of clarity, or an inability to distinguish between the various sounds in spoken language. (The word is *CLEARNESS.*)

Conductive hearing loss associated with pathology in the external or middle ear generally affects a person's ability to hear at normal loudness levels. It does not usually impair the clarity with which that person hears once the sound is made loud enough to compensate for the hearing loss. The key to clarity in hearing is held by the inner ear mechanism and the nerve fibers that carry the message to the brain.

When damage occurs to the inner ear or auditory nerve, the resulting sensorineural hearing loss can affect not only the perceived loudness of incoming sounds, but also their clarity. Speech in particular can seem unclear or distorted regardless of how loud it is. The main complaint associated with this type of hearing loss is that patients can "hear" but cannot understand, especially in the presence of background noise. This occurs because the tiny hair cells that respond to specific speech sounds are so severely damaged that they cannot react when the vibrations from sound waves strike them while hair cells for other speech sounds may be functioning normally.

Speech Sounds

Speech sounds can be classified as vowels or consonants. The vowel sounds—located in the lower frequencies—are the more powerful speech sounds. Therefore, vowels carry the energy for speech. In contrast, consonants—located in the higher frequencies—are important in distinguishing one word from another. This is the heart of the communicative problem for people with noise-induced (high-frequency) hearing loss. They are often unable to distinguish between similar words such as *stop* and *shop*. If one word in a sentence is mistaken for another, the entire meaning of the sentence may be misunderstood, leading to embarrassing situations.

Background Noise

People with high-frequency hearing loss often manage fairly well in quiet listening situations. However, in a noisy environment, such as in traffic, in a restaurant, or on the job, it can become extremely difficult to communicate through hearing alone.

A listener with normal hearing can hear a speaker in the presence of typical background noise with little or no difficulty. However, if the listener developed a hearing loss for all speech sounds above 1,000 Hz, there would be a marked decrease in that person's ability to hear the speaker clearly. Most ambient (background) noise is low frequency. Since there is more energy in the low frequencies, the noise masks the weaker, high frequency speech sounds, so crucial for clarity, making it even more challenging to understand what is being said.

Quality of Life

Most often noise-induced hearing loss occurs gradually, over time. In the initial stages the person may experience little

difficulty in most situations. However, as the hearing loss increases in severity and affects more frequencies, the hearing-impaired individual often begins to avoid certain situations (such as parties) and may have a tendency to withdraw socially. Everyday situations, such as listening to the grandchildren or talking to a spouse while the television is on, become sources of frustration.

Rehabilitation

There is no medical or surgical cure for sensorineural hearing loss. However, much can be accomplished with amplification (hearing aids) and counseling to minimize the effects of the hearing impairment on the quality of life.

The hearing aids of today are a vast improvement over the hearing aids of the past, although they are still unable to compensate completely for the lost hearing. New technology and fitting techniques make it possible to finely tune a hearing aid by adjusting a series of parameters to compensate for the uniqueness of each person's hearing loss. This allows a hearing-impaired user to hear more naturally and with less interference from background noise.

Counseling is a crucial component of aural rehabilitation. An explanation of the hearing test results, options regarding amplification, a discussion of realistic expectations, and tips for easier communication are all beneficial in helping the individual to live comfortably with the hearing impairment.

Further Medical Evaluation

When should an individual be referred to a physician for further medical evaluation? The American Academy of Otolaryngology-Head and Neck Surgery recommends referral for evaluation of significant hearing loss (or other ear problems) as follows:

HEARING LOSS

- Baseline audiogram
  - Average hearing level at 500, 1,000, 2,000, and 3,000 Hz is greater than 25 dB in either ear; or,
  - Difference in hearing level between the ears of more than 15 dB at 500, 1,000, and 2,000 Hz or more than 30 dB at 3,000, 4,000, and 6,000 Hz
- Periodic audiogram
  - Change of average hearing (for the worse) in either ear compared to the baseline of more than 15 dB at 500, 1,000, and 2,000 Hz, or more than 20 dB at 3,000, 4,000, and 6,000 Hz

OTHER

- Ear pain; drainage; dizziness; severe persistent tinnitus; sudden, rapidly progressive or fluctuating hearing loss; a feeling of fullness or discomfort in the ear within the preceeding 12 months
- Excessive cerumen accumulation or foreign body in the ear canal

EVALUATING IMPAIRMENT: *THE AMA GUIDES*

Chapter 11.2 of the American Medical Association's *Guides to the Evaluation of Permanent Impairment* includes criteria for evaluating permanent impairment resulting from damage to the ear's hearing and/or vestibular functions. This determination is important in assessing employability and compensation for loss of function due to injury (e.g., workers' compensation). Because many state agencies have adopted the use of the AMA formula for determining hearing impairment, it is important that the industrial hygienist or occupational clinician understand it.

In these *Guides,* permanent impairment of any particular body part or system is expressed in terms of the capacity of the whole person to perform activities of daily living. The actual level of function should be determined without the aid of a prosthetic device (in this case, a hearing aid). Equilibrium and hearing are considered separately. Only general criteria are provided for disturbances of equilibrium, but the criteria for evaluating hearing impairment are relatively specific.

Hearing loss for each ear is calculated at thresholds of 500, 1,000, 2,000, and 3,000 Hz. No allowance is made for impairment of speech discrimination due to deficits at higher frequencies. The *Guides to the Evaluation of Permanent Impairment* include a formula for calculating the binaural hearing loss based on the percentage impairment of each ear, tested separately. Each ear must have an average hearing shift of more than 25 dB for the frequencies measured to be ranked as impaired. The percentage of impairment of the poorer ear is added to five times the percentage of impairment of the better ear and the total divided by six. Thus, a person with normal hearing in one ear (0 % impairment) but totally deaf in the other (100 % impairment) would have a binaural hearing impairment of 17 percent ([(5 x 0 %) + 100 %]) ÷ 6 = 17 %). In our example, the 17-percent binaural impairment translates into a 6-percent whole-person impairment.

OSHA HEARING CONSERVATION PROGRAM (29 *CFR* 1910.95)

On April 7, 1983, the Hearing Conservation Amendment (HCA), included in the *Federal Register 29 CFR* 1910.95, became effective. The Occupational Health and Safety Administration (OSHA) Noise Regulation provides specifics on the content of required hearing conservation programs. The regulation covers the following:

- Noise monitoring
- Audiometric testing program
- Definition of standard (permanent) threshold shift
- Employee follow-up and referral
- Hearing protection
- Employee training
- Recordkeeping

This amendment requires that all OSHA-covered workers be included in hearing conservation programs if they are exposed at or above an eight-hour time-weighted average (TWA) of 85 dBA or more. Chapter 9 contains a complete discussion of the requirements of the HCA. Unfortunately, a number of people develop threshold shifts on prolonged exposure to levels as low as 80 dBA. For a discussion of compensation laws as they relate to hearing, see Chapter 9, Industrial Noise.

SUMMARY

The sophisticated hearing and vestibular functions of the ear are linked to the anatomy and physiology of the external, middle, and inner ear. Damage to the external and middle ear can cause conductive hearing loss. Sensorineural hearing loss and/or equilibrium problems are consequences of dysfunction of the inner ear components. Hearing problems can be diagnosed and monitored through the use of precise, standardized audiometric testing. Occupational hazards, particularly noise, are capable of inducing temporary and permanent hearing loss. Hearing loss of any cause can have devastating effects on an individual's general well-being.

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Chapter 5

The Eyes

by George S. Benjamin, MD, FACS
revised by Allison S. Zaum, OD, MPH, CIH (retired)

The eye may be the organ most vulnerable to occupational injuries. Although the eye has some natural defenses, they do not compare with the healing properties of the skin, the automatic cleansing abilities of the lungs, or the recuperative powers of the ear. Consequently, the eye is at greater risk and eye and face protection is a major occupational health issue.

The demands placed on the eye in modern workplaces and practices, such as prolonged viewing at close distances or at distances neither near nor far, are great. Both of these conditions can cause acute and chronic eye fatigue and visual discomfort. Hazardous substances can be absorbed into the eye system. Machinery, if guarding mechanisms fail, can propel objects capable of causing traumatic injury to the eye. In 1998, the Bureau of Labor Statistics reported 58,526 total cases of lost-time injuries or illnesses related to the eyes. The incidence rate was 6.6 per 10,000. These statistics represent only the OSHA-reportable injuries and illnesses.

The eye, with its remarkable ability to translate radiant light energy into neural impulses, which are transmitted to the visual cortex of the brain, is certainly one of the most valued organs. Protection of the sensory organs of this complex system should be a high priority in every occupational health and safety program.

ANATOMY

A look at the structure of the human eye and how it can be affected by industrial hazards clarifies the need for eye protection programs. The eyeball is housed in a cone of cushioning fatty tissue that insulates it from the skull's bony eye socket. The skull has brow and cheek ridges projecting in front of the eyeball, which is composed of specialized tissue that does not react to injury like other body tissue (Figure 5–1).

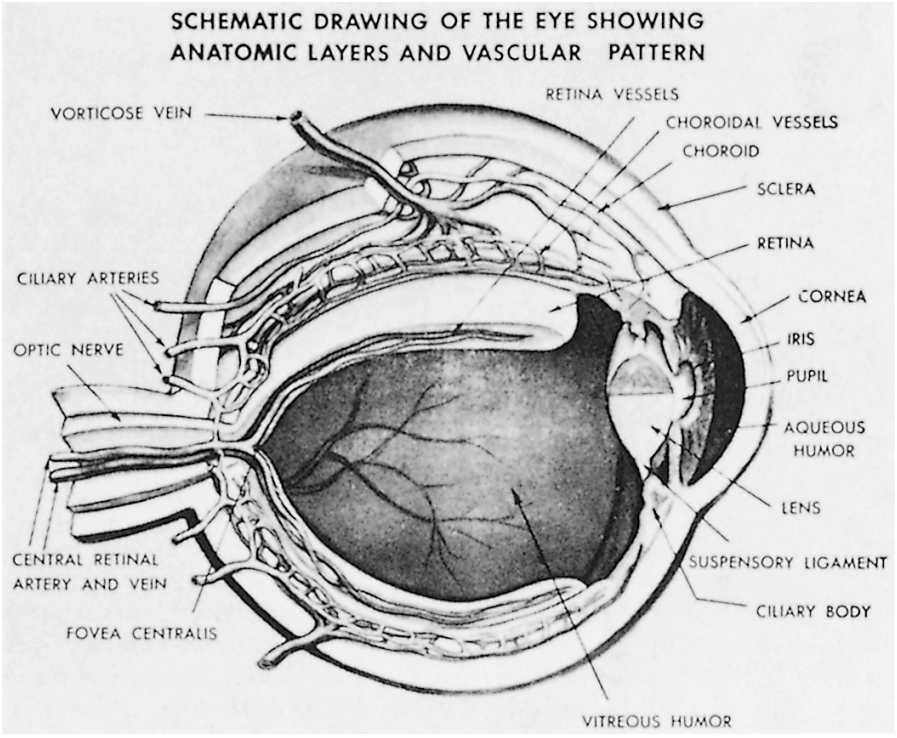

Figure 5–1. Schematic drawing of the eye showing anatomic layers and vascular pattern. (Reprinted with permission from the American Medical Association, *The Wonderful Human Machine.* Chicago: AMA, 1971.)

Eyeball

The eyeball consists of three coats, or layers, of tissue surrounding the transparent internal structures. There is an external fibrous layer, a middle vascular layer, and an inner layer of nerve tissue.

The outermost fibrous layer of the eyeball consists of the sclera and the cornea. The sclera, also called the white of the eye, is composed of dense fibrous tissue and is the protective and supporting outer layer of the eyeball. In front of the lens this layer is modified from a white, opaque structure to the transparent cornea. The cornea is composed of dense fibrous connective tissue and has no blood vessels. The cornea must be transparent to let light through to the receptors in the eyeball.

The middle vascular layer of the eyeball is heavily pigmented and contains many blood vessels that help nourish other tissues.

The nerve layer, or retina, is the third and innermost layer of the eyeball. Toward the rear, the retina is continuous with the optic nerve; toward the front, it ends a short distance behind the ciliary body in a wavy border called the ora serrata. The retina is composed of two parts: the outer part is pigmented and attached to the choroid layer and the inner part consists of nerve tissue.

The front of the eyeball is protected by a smooth, transparent layer of tissue called the conjunctiva. A similar membrane covers the inner surfaces of the eyelids. The eyelids also contain dozens of tiny tarsal glands that secrete an oil to lubricate the surfaces of the eyeball and eyelids. Still further protection is provided by the lacrimal gland, located at the outer edge of the eye socket. It secretes tears to clean the protective membrane and keep it moist (Figure 5–2).

The region between the cornea and the lens is filled with a salty, clear fluid known as the aqueous humor. The eyeball behind the lens is filled with a jelly-like substance called the vitreous humor.

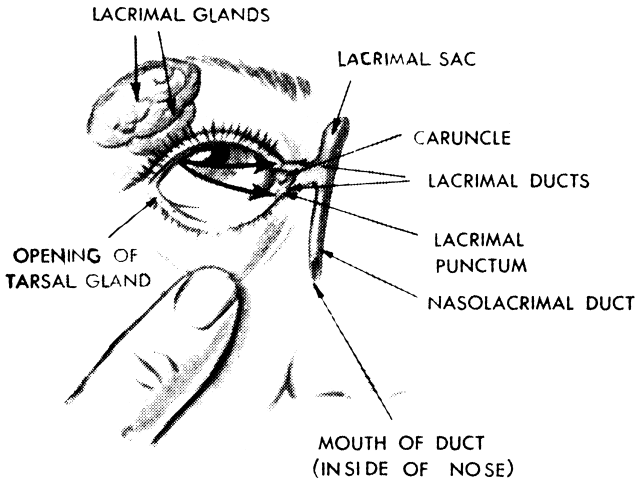

Figure 5–2. Illustration of the eye and tear ducts. (Reprinted with permission from the AMA, *The Wonderful Human Machine.* Chicago: AMA, 1971.)

Light rays enter the transparent cornea and are refracted at the curved interface between air and the fluid bathing the cornea. After passing through the cornea and the clear liquid, (the aqueous humor, contained in the anterior chamber), the bundle of rays is restricted by a circular variable aperture, the pupil. Its size is changed by action of the iris muscles.

The light rays are further refracted by passage through the lens, traversing the clear, jelly-like vitreous humor, so that, in a properly focused eye, a sharp image is formed on the retina. Scattering of light within the eye is minimized by a darkly pigmented layer of tissue underlying the retina, called the choroid. The choroid contains an extremely rich blood supply that is believed to dissipate the heat resulting from absorbed light energy. The shape of the eyeball is maintained by its enclosure in an elastic capsule, the sclera, and by the fluids within that are maintained at positive pressure.

The lens is attached by suspensory ligaments to the ciliary body, a muscular organ attached to the sclera. The ciliary body muscles alter the lens shape to fine-focus the incoming light beam. Ordinarily, these muscles are active only when looking at objects closer than 20 ft (6.1 m). Consequently, when doing close work, it is restful to pause occasionally and look out a window into the distance. Many complaints of eye fatigue are really complaints about tired ciliary muscles. The pigmented iris, overlying the lens, is a muscular structure designed to expand or contract and thus regulate the amount of light entering the eye. The circular aperture formed by the iris is called the pupil.

The aqueous and vitreous humor and other eye tissues are composed primarily of water, so their absorption characteristics are similar to those of water.

Retina

The retina, a thin membrane lining the rear of the eye, contains the light-sensitive cells. These cells are of two functionally discrete types: rods and cones. They get their names from the rod and cone shapes seen when the layer is viewed under a microscope. The rods are more sensitive to light than the cones; the cones are sensitive to colors.

There are more rod cells than cones; each eye has about 120 million rods and only 6 million cones. The rods are incapable of color discrimination because they contain a single photosensitive pigment. There are fewer cone cells, and they are less sensitive to low levels of luminance. There are three types of cones in the human eye; each contains a different photopigment, with peak response to a particular part of the visible spectrum. Thus, by differential transmission of nerve impulses on stimulation, the cones encode information about the spectral content of the image so that the observer experiences the sensation of color. About four percent of the population (95 percent of whom are male) inherits a defect in one of the cone pigments, so that the wavelength of maximum absorption is somewhat shifted. People with these color defects are not color "blind," as they do see colors, but rather are color defective, in that they perceive certain colors differently from people with "normal" cone pigments.

Binocular Vision

Binocular vision refers to vision with two eyes. The advantages of binocular vision are a larger visual field and a perception of depth, or stereoscopic vision. There is a slight difference in the images on the two retinas; there is a right-eyed picture on the right retina and a left-eyed picture on the left retina. It is as if the same landscape were photographed twice, with the camera in two positions a slight distance apart. The two images blend in consciousness and give us an impression of depth or solidity. Binocular vision is not identical to depth perception but is an important clue to that visual function. Depth perception is further discussed in the section on visual performance of this chapter.

EYE PROBLEMS

Specialists in the field of vision include *ophthalmalogists, optometrists,* and *opticians*. They use a variety of tests and instruments to examine a person's visual status, including the Snellen chart to test for distance acuity, ophthalmoscope, slit-lamp microscope, tonometer, perimeter, gonioscopic lens, and phoropter.

Specialists

OPHTHALMOLOGIST

The American Academy of Ophthalmology defines an *ophthalmologist* as a doctor of medicine (MD) who specializes in the comprehensive care of the eye and visual system. Each is licensed by a state to practice medicine and surgery.

OPTOMETRIST

The American Optometric Association defines an *optometrist* (Doctor of Optometry, or OD) as a primary healthcare provider who diagnoses, manages, and treats conditions and diseases of the human eye and visual system. All states now permit optometrists to prescribe certain therapeutic pharmaceuticals and provide treatment for ocular diseases; the specifics vary with each state. Both ophthalmologists and optometrists prescribe eyeglasses and contact lenses.

OPTICIAN

The Opticians Association of America defines an *optician* as an individual who manufactures, verifies, and delivers lenses, frames, and other specially fabricated optical devices.

Examining Instruments

The vision tests used in industrial preplacement examinations are screening tests. They detect possible problems in visual performance and are not by themselves diagnostic. They should not be the basis of any job restrictions without further evaluation by a qualified ophthalmologist or optometrist and consideration of reasonable accommodations.

Snellen Chart

The most common industrial test for distance acuity is the

Snellen wall chart in its several variations. The Snellen chart consists of block letters in diminishing sizes so that at various distances, the appropriate letter subtends a visual angle of five minutes at the nodal point of the eye. Thus, the top large letter appears to be the same size when it is 200 ft (61 m) away as the standard appears at 20 ft (6.1 m).

The distance of 20 ft (6.1 m) is considered to be infinity. This means that the rays of light coming from an illuminated object are parallel; they neither diverge nor converge. If the object is closer than 20 ft (6.1 m), the light rays diverge and must be made parallel by action of the lens within the eye or by the addition of a supplementary lens held in front of the eye; otherwise, they do not come to a sharp focus on the area of central visual acuity of the retina.

The cornea and lens of the eye bend the parallel rays to converge to a focus on the retina. Looking at an object at 20 ft (6.1 m) or more, the normal lens is relaxed into its usual biconvex shape. The parallel rays of light that are bent (refracted) by the cornea and lens cross at the nodal point of the eye (about 7 mm behind the cornea) and, continuing their straight course, fall on the retina, forming an inverted image.

It is important to check several factors. The distance from the chart to the person being tested must be 20 ft (6.1 m), or 10 ft (3 m) if a mirror and reversed chart are used. The lighting should be uniform, its source not visible to the person being tested. The chart should be clean. Finally, the tester must be trained to hold the cover correctly over the eye not being tested, to vary the order of lines and letters, and to be alert for any unusual factors. It is important to separately test and record the vision of each eye and the vision when reading the chart with both eyes.

Satisfactory vision at a distance does not ensure adequate near-point vision, so it is important to recognize near-point abnormalities. Many industrial work situations involve near-point seeing even though they are not confined to near-point work.

Industrial vision testing should be done with standardized tests to detect and identify substandard visual functions. Accuracy is vital, since workers with visual defects can put themselves and others at risk. A competent examination of the eyes requires the use of a number of special examining instruments.

- An *ophthalmoscope* permits study of the interior structures of the eye, such as the retina, optic nerve, and vitreous.
- A *slit-lamp microscope* allows study of the anterior segment of the eye, and with the use of additional lenses, the posterior (interior) structures of the eye as well.
- A *tonometer* is used to measure the pressure in the eyeball (one of the tests for glaucoma).
- A *perimeter* is used to map the limits of the fields of vision.
- A *gonioscopic lens* views the angle of the anterior chamber where the outflow drainage apparatus of the eye is found.
- A *phoropter* is used to determine refractive correction (eyeglass prescription) and binocular vision abnormalities. It consists of test lenses and prisms that are added and removed using both objective criteria and subjective responses (Figure 5–3).

Eye Defects

A 1995 study by Lighthouse International compiled statistics on visual impairments in the United States. Approximately 1.1 million Americans (0.5 percent) are considered legally blind, as defined by clinical measurement (a visual acuity with corrective devices of 20/200 or less, or a visual field in the better eye of 20 degrees or less). In addition, more than 10 million people (about one in every 20) in the United States suffer from significant impairment of vision which cannot be improved by corrective lenses. This condition is designated as "low vision." The leading causes of existing cases of blindness are glaucoma, macular degeneration, cataracts, atrophy of the optic nerve, diabetic retinopathy, and retinitis pigmentosa. These causes account for 51 percent of all cases of blindness, according to the National Society to Prevent Blindness. The leading causes of new cases of blindness are macular degeneration, glaucoma, diabetic retinopathy, and cataract; combined, these account for 52.5 percent of all new cases. A large percentage of all cases of blindness could be prevented by taking advantage of current medical technology and proper safety measures.

It has been estimated that 40 percent of the population wear glasses, indicating that nearly one in two people have some visual defect. Three common eye defects—farsightedness, nearsightedness, and astigmatism—are the results of simple optical aberrations in the eye. Additionally, with the aging of America, *presbyopia,* the age-related decrease in near vision, will affect an increasingly larger segment of the population.

FARSIGHTEDNESS

When the eyeball is too short from front to back, the light rays come to a focus behind the retina. Light rays coming from a distant object may reach their focus at the retina, so that distant vision is good, but near vision is blurred. This condition is called farsightedness or *hyperopia*. The treatment is to wear a convex lens that converges the light rays from near objects so that they are brought to a focus on the retina (Figure 5–4).

NEARSIGHTEDNESS

If the eyeball is too long from front to back, as it is in nearsightedness, or *myopia,* the image of an object 20 ft (6.1 m) or more away falls somewhere in front of the retina. The eye can focus on it sharply only by looking through a concave lens, which diverges the rays coming from the object. By bringing the object near enough to the eyes, a myopic person can get a good focus (Figure 5–5).

Figure 5–3. A phoropter is used with a set of test lenses to find which ones aid vision. (Photograph reprinted with permission of Reichert Ophthalmic Instruments.)

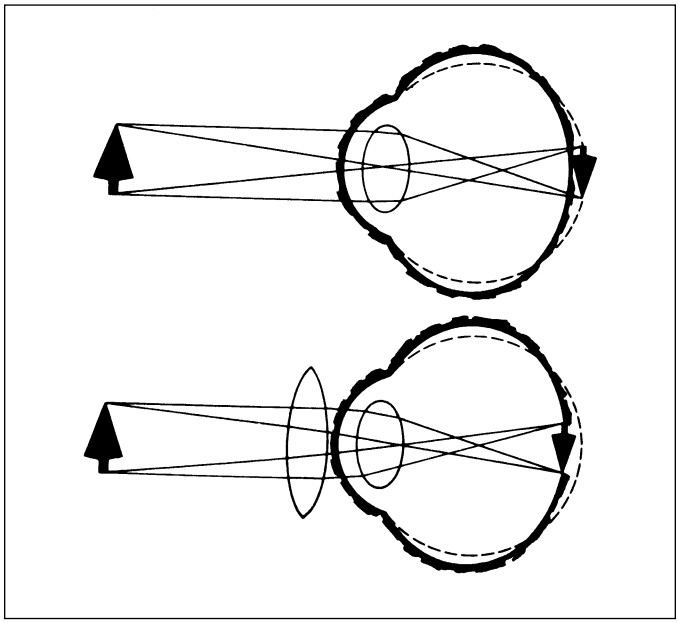

Figure 5–4. In farsightedness, or hyperopia, the eyeball is too short, so the image of an object is focused behind the retina. A convex lens brings the light rays into focus on the retina. Although hyperopic people may be able to see things sharply by thickening the lens of the eye (accommodation), this involves effort of inner muscles of the eye and may cause eye fatigue. (Reprinted with permission from Cooley DG, ed. Family Medical Guide. New York: Better Homes and Gardens Books, 1973.)

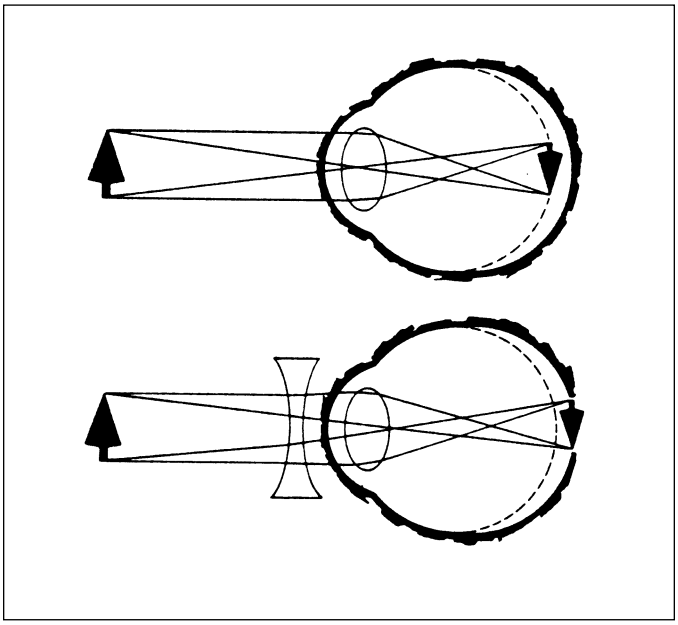

Figure 5–5. In nearsightedness, or myopia, the image of an object (unless it is held close to the eyes) falls in front of the retina instead of on it, and the object is seen indistinctly. The condition is corrected by using a concave lens of proper curvature to bring the image into focus on the retina. (Reprinted with permission from Cooley DG, ed. Family Medical Guide. New York: Better Homes and Gardens Books, 1973.)

ASTIGMATISM

If the curvature of the cornea is irregular so that some rays of light are bent more in one direction than in another, the resulting image is blurred because if one part of the ray is focused, the other part is not. This is something like the distortion produced by a wavy pane of glass, and is called *astigmatism.* It is corrected by using a lens that bends the rays of light in only one diameter (axis). This lens is called a cylindrical lens and it can be turned in the trial frame to its proper axis to even up the focusing of the light rays in all parts. (Figure 5–6)

A person can have astigmatism in addition to either nearsightedness or farsightedness. Small amounts of astigmatism that do not severely affect distance vision may cause eyestrain for people who spend prolonged time working at a computer. "Computer glasses" may be indicated for such individuals.

PRESBYOPIA

The closer an object is brought to the eye, the more convex the human eye lens must become in order to focus on it. Through aging, the human lens loses its accommodative power, that is, its elasticity and its power of thickening. This condition is known as *presbyopia,* and usually develops after age 40 years. A common symptom is finding that our arms are too short to read a book. Nearsighted individuals may find they need to remove their spectacles for reading or other close work. Farsighted people, many of whom who never needed glasses before, will start to experience near blur or eyestrain while working at the computer.

Presbyopia is corrected by wearing convex lenses, often in a bifocal or other multifocal lens. The reading prescription (or "add") gets progressively higher until around the age of 55 years, when it generally stabilizes.

Eyeglasses

The purpose of wearing eyeglasses is to help focus the rays of light on the retina. Glasses cannot change the eye or produce any disease even if they are badly fitted.

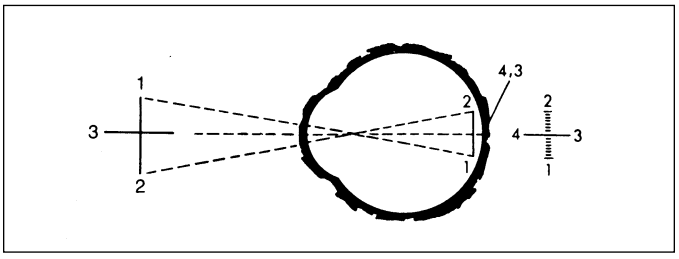

Figure 5–6. Astigmatism resulting from irregular curvature of the cornea is something like distortion produced by a wavy pane of glass. Drawing shows light rays (3,4) in sharp focus on retina, with light rays (1,2) focused in front of the retina, resulting in a blurred image. The small diagram on the right shows horizontal image in focus, vertical image out of focus. A cylindrical lens placed in the proper axis to bring light rays to even focus corrects astigmatism.

A prescription for glasses may look something like this:

+ 2.50 – 0.50 x 180

The + sign indicates a convex lens suitable for a farsighted person. A – sign would indicate a concave lens for a myopic person. The *2.50* indicates the *diopters,* which indicate the strength or power of the lens. A diopter (D) is a unit of measurement of the refractive or light-bending power of a lens. The normal human lens in its relaxed biconvex shape has a power of about 10 D.

Thus, the prescription in the example means that the optician grinds a convex spherical lens of 2.50 diopters combined with a concave cylindrical lens of half a diopter (0.50) situated horizontally (axis 180 degrees). Lens prescriptions look strange, but opticians everywhere know what they mean.

Bifocal or other multifocal lenses (such as progressive or "no line bifocal" lenses) also include a prescription for reading, called an addition or "add." If the person with the above hyperopic (farsighted) correction also needed 2.00 diopters additional to read, the prescription would read as follows:

+ 2.50 – 0.50 x 180 with + 2.00 add

VISUAL PERFORMANCE

Normal visual performance involves a number of interdependent discriminations made in response to the visual environment and mediated by the visual system.

Visual Acuity

There are many definitions of the term *visual acuity;* all, however, incorporate the concept of detail resolution. Many test patterns have been used to measure acuity, from single dots to twin stars, gratings, broken rings, checkerboards, and letters. The Snellen Letter Test is probably the most familiar and is widely used. The most satisfactory expression for visual acuity is the amount of critical detail that can just be discriminated.

Some important variables affecting visual acuity are as follows:

LUMINANCE

The level of adaptation of the eye has a profound effect on visual acuity.

POSITION IN THE FIELD

At photopic levels, acuity is best at the fovea and drops off as the retinal periphery is approached because there are fewer cones at the periphery. Nocturnal acuity is quite poor, with essential blindness at the fovea and best resolution in the periphery, where rods are more plentiful. This can be appreciated when looking at stars, as a star can often be detected more clearly when viewed peripherally than straight on.

DURATION

When the pattern is viewed for only a short time, measured acuity diminishes.

CONTRAST

Visual acuity decreases as the contrast between pattern and background diminishes. The strength of this correlation depends on the adapting luminance. People with visual disorders often have reduced contrast sensitivity but reasonable Snellen acuities; some states are requiring contrast sensitivity testing for driver's licenses, in addition to acuity.

Dark Adaptation

Optimal visual discrimination under conditions of very low light can be made only if the eyes are adapted to the level of the prevailing light or lower. If a fully light-adapted eye is suddenly plunged into darkness, its initial sensitivity is poor. With time, however, sensitivity increases as a result of photochemical regeneration, certain functional neural changes, and, to a much smaller degree, enlargement of the pupil. After the eye remains in total darkness for 30–60 minutes, the adaptation process is nearly complete; the sensitivity of the eye in parts of the retina where both rods and cones are present is increased by a factor of 10,000 for white light.

There are several important operational consequences of the dark adaptation process:

- ➢ Best performance on a task in low light requires that the eye be preadapted to an appropriately low level long enough to attain maximum sensitivity.
- ➢ Because the rods are more sensitive than the cones at low light levels, detection capability is highest on the parts of the retina where rods abound (10–30 degrees from the fovea) and averted vision is required for optimal performance.
- ➢ Because the rods are relatively insensitive to extreme red wavelengths, dark adaptation is facilitated if the observer wears red goggles or if the illumination provided is a very deep red, as in a spacecraft or photographic darkroom. By this means, the observer can continue to use the high-acuity capability of the central fovea at elevated luminance levels for reading instruments and such while the adaptation process goes on, although vision naturally is monochromatic in this case.
- ➢ Because the two eyes are essentially independent in adaptation, it is possible to maintain dark adaptation in one (using an eye patch, for example) while the other is used at high light levels.

Depth Perception

Depth can be estimated by an experienced observer through use of various cues. Some of these cues are provided by the nature of the scene of interest; others are inherent in the observer.

In cases where only internal cues to distance are available—that is, when objects of interest are of unknown size and shape—the observer must depend on his or her stereoscopic acuity, accommodation, and convergence, and, where possible, movement parallax. Accommodation is the only effective cue to distances at ranges of a meter or less, and even here it is inaccurate. Convergence (bringing the eyes toward the nose) alone is a somewhat more useful cue, but only within about 20 m of the observer. Stereoscopic acuity provides a powerful clue to distance, but it should not be assumed that people with monocular vision cannot do tasks normally assumed to require stereoscopic vision; actual performance should be tested. Certain jobs (e.g., pilots), however, do require a minimum amount of depth perception.

Commercially available stereopsis tests include the Titmus "Fly"and the Randot stereo test (available from Bernell and other suppliers).

Color Vision

Color deficiencies can impose restrictions in certain occupations. These include electricians, pilots, commercial drivers, firefighters, dye workers, and many other professions. A commonly administered test is the Ishihara color plate test. These plates are extremely sensitive at identifying red-green defects, the most common inherited color defects. Another color test is the Farnsworth D-15 Panel Test. In this test, the subject arranges a series of colored caps. Some employers accept individuals with a color deficiency if they can pass certain "trade tests," such as the FALANT (Farnsworth Lantern Test), used to evaluate recognition of aviation and maritime colored signal and marker lights. People with mild or borderline color deficiencies may be able to demonstrate sufficient color vision for a particular job by passing the D-15 Panel.

Even when color discrimination is not a job criterion, baseline color vision testing for all employees is useful, in that it can help distinguish between inherited color defects from those that are acquired (caused by disease).

A very small percentage of the population is truly "color blind," in that they have no cones in their retinas, only rods. This condition is called *rod monochromatism*. These people are extremely photophobic and have very decreased visual acuity. They usually need to wear tinted glasses for comfort, and may require additional occupational modifications and low vision aids.

EYE DISORDERS

There are numerous eye disorders. Conjunctivitis, infections, uveitis, glaucoma, cataracts, sensitivity to excessive brightness, night blindness, eyestrain and nystagmus are among the disorders most commonly encountered. They are briefly described.

Conjunctivitis, Infections, and Uveitis

Various types of conjunctivitis, or inflammation of the mucous membrane, can develop beneath the eyelids. The eye becomes scratchy and red and has a discharge. Most often the cause is viral, bacterial, or allergic. All causes produce varying degrees of redness, which is often referred to as "pink eye." Viral infections usually produce tearing, bacterial infections

cause pus or mucous discharge, and allergic reactions cause itching and occasionally a "stringy" discharge.

Bacterial, viral, or fungal infections can affect the cornea. They can cause pain, decreased vision, and photophobia (light sensitivity). Contact lens wearers are particular susceptible to bacterial infections. Employees presenting with red eyes should be immediately evaluated by an eye care practitioner, as there are bacterial strains that can penetrate an intact cornea within 24 hours.

A fairly common type of infection, especially in adults, is caused by the herpes simplex virus on the anterior surface of the eyeball. This can lead to blurred vision, scarring, and permanent damage to vision. It may affect one or both eyes and quite often recurs. Topical steroids often used for other types of conjunctivitis greatly aggravate herpes infections. Therefore, any signs suggesting inflammation near the cornea should be immediately referred to an eye care practitioner experienced in treating eye disorders.

Inflammation of the interior eye is common in adults. One of the most common areas of infection is the uveal tract, which is the middle coat of the eye. Inflammation of this type damages the retina, the lens, and the cornea. The cause of a uveal inflammation (or *uveitis*) is often idiopathic, but can also be associated with diseases of the joint, lung, or intestinal tract. A search must be made for disease elsewhere in the body that might be the cause of the eye problem. When found, the primary cause should be treated. The eye should also be treated to prevent damage to vision. Once again, an employee presenting with a red, painful, and photophobic eye should be immediately evaluated by an eye care practitioner.

Glaucoma

Glaucoma is a leading cause of blindness in America. The most common form, *primary open-angle glaucoma* (POAG), was originally thought to develop when the fluid that normally fills the eyeball, the aqueous humor, fails to drain properly. Ordinarily, the fluid is continuously produced in the eye and excess drains off through a small duct near the iris. Aging, infection, injuries, congenital defects, and other causes can constrict or block the duct. Fluid pressure then builds up and the pressure, if great and of long duration, can damage the optic nerve. Recent research has hypothesized that reduced blood perfusion to the optic nerve may be a potential cause of POAG.

In another form of the disease, *acute-angle closure glaucoma,* vision dims suddenly, the eyeball becomes painful and very light-sensitive, and the patient feels quite ill. An angle closure attack should be considered an ocular emergency. However POAG causes no pain, injuring vision very slowly. Sometimes symptoms include the perception of colored rings and halos about bright objects or dimming of side vision.

Much can be done to preserve vision in most cases when glaucoma is diagnosed early. Medication is often effective in controlling the pressure. In recalcitrant cases, laser treatment or filtering surgery may be indicated.

Cigarette smoking has been shown to increase the risk of developing glaucoma, providing yet another reason to counsel employees about the hazards of smoking.

Cataracts

Cataracts are opacities that form on the lens and impair the vision of many elderly and some younger people. Many cases are associated with metabolic disease or aging, but there are also traumatic cases associated with industrial exposures to ionizing radiation, ultraviolet radiation, infrared radiation, foreign bodies, and certain chemicals. Cataracts can also be caused by certain medications, particulary prolonged treatment with corticosteroids. There is also evidence that cigarette smoking increases cataract development. If the vision impairment is severe, the diseased lens can be removed, and is generally replaced with a plastic implant.

Excessive Brightness

Good sunglasses can protect the eyes in bright sunlight. Poor ones compound or create problems. Glasses with scratches and irregularities should not be used. Some glasses are too lightly tinted to do much good; good glasses reduce the invisible as well as the visible light. (Injury from light will be discussed later in this chapter under irradiation burns.) In addition to helping relieve discomfort caused by glare, sunglasses provide important protection to the anterior and posterior structures of the eyes.

Night Blindness

Inability to see well or at all in dim light can mean something is wrong not only with the eye but with the entire visual system. Night blindness, as it is called, is a threat to safety, particularly on the highway, because a driver may have 20/20 vision and not realize that his or her vision is somewhat impaired at night. The condition produces no discernible change in eye tissues, so it cannot be diagnosed unless a patient tells the physician of difficulty in reading road signs or picking out objects at night. It is not normal to have trouble seeing in dim light because sufficient accommodation occurs in two or three minutes.

Eyestrain

Eyestrain can lead to severe signs of local irritation, headaches, fatigue, vertigo, and digestive and psychological reactions. This condition can result from a need for eyeglasses or from using glasses with the wrong correction. Eye muscle strain may also result from unfavorable conditions such as improper lighting while reading or doing close work. To avoid strain when reading, do not face the light; it should come from behind and to the side. Be sure light bulbs are strong enough (75–100 watts). Hold the book or paper about 16–18 in. (0.4 m) away and slightly below eye level. Avoid glare and occasionally rest the eyes by shifting focus and looking off into the distance. ANSI/ IES-RP-7 provides detailed recommendations for the design of industrial lighting.

Nystagmus

Nystagmus, involuntary movement of the eyeballs, may occur among workers who, for extended periods, subject their eyes to abnormal and unaccustomed movements. Complaints of objects dancing before the eyes, headaches, dizziness, and general fatigue are associated symptoms; all can clear up quickly if a change of work is made. The involuntary movements of the eyeball characteristic of nystagmus can sometimes be induced by occupational causes affecting the eyes through the central nervous system or by some extraneous cause. The most prevalent form of occupational nystagmus is seen in miners.

PHYSICAL HAZARDS

The eye is subject to many kinds of physical injury—blows from blunt objects, cuts from sharp objects, and damage from foreign bodies.

Blows from Objects

A blow from a blunt object can produce direct pressure on the eyeball or, if the object delivering the blow seals the rim of the bony orbit on impact, it can exert hydraulic pressure. Such blows may cause contusion of the iris, lens, retina, or even the optic nerve. Violent blows might rupture the entire globe or fracture the thin lower plate of the bony orbit, entrapping the eye muscles.

Contusions may result in serious, irreversible injury if not treated promptly and adequately. Hemorrhaging releases blood, which can be toxic to eye tissues, and physical dislocations of lens, retina, and other parts are unlikely to repair themselves. Lacerations of the cornea, lid, or conjunctiva can be caused by any sharp object, from a knife to the corner of a piece of typing paper.

Corneal Lacerations and Abrasions

Corneal lacerations, if full-thickness, may allow the aqueous solution behind the cornea to gush out until the iris, which has the consistency of wet tissue paper, is pulled toward the laceration and plugs the wound. The iris can be put back in place, the laceration sutured, and the eye made nearly as good as new. More common corneal injuries are scrapes or abrasions that do not penetrate to the chamber behind the cornea. Such abrasions are very painful, but heal within several days if treated properly. If they are too deep or allowed to become infected, scars that interfere with vision result.

Lacerations of the lid heal, but the scar tissue can pull the lid into an unnatural position. In addition to cosmetic deformity, the lids might not close completely or lashes might turn in against the eyeball. Vertical lacerations are more serious in this respect.

Because it is composed of highly differentiated tissues, the eye is more likely than a finger to suffer permanent damage from injury. This does not mean the eye has no natural defenses. The bony ridges of the skull protect the eyeball from traumatic injury caused by massive impact. A baseball, for instance, is too big to crush the eyeball—it is stopped by the bony orbit. The cushioning layers of conjunctiva and muscle around the eyeball absorb impact. The fact that the eyeball can be displaced in its socket is also a defense against injury. In addition, the optic nerve is long enough to allow some displacement of the eyeball without rupture of the nerve.

Blink Reflex

The eye is most vulnerable to attack at the corneal surface. Here, the eye is equipped with an automatic wiper and washer combination. The washers are the lacrimal glands; the wiper is the blinking action.

The teary blink washes foreign bodies from the corneal or conjunctival surfaces before they can become embedded. The triggering mechanism is irritation.

The reflex blink can also act like a door to shut out a foreign object heading for the eye if the eye can see it coming and it isn't coming too fast. Protective equipment for the eye is used in industry to improve or extend these natural defenses. These defenses might be adequate protection against light and small foreign objects and small quantities of mildly toxic liquids, but they are no match for industrial eye hazards such as small high-speed particles or caustic powders and liquids.

Foreign Bodies

Invasion by a foreign body is the most common type of physical injury to the eye. Not all foreign bodies, however, affect the eye in the same way.

Foreign bodies affecting the conjunctiva are not usually very serious. They may result in redness and discomfort, but not vision damage. Bodies on the conjunctiva, however, can be transferred to the cornea and become embedded if a person rubs the eye. Even with minor irritations of the conjunctiva, a trip to the nurse is advisable. If there is obvious irritation and no object can be found, it is advisable to see a physician immediately.

Some industrial eye injuries may appear trivial, but can become serious due to complications. The most common complication is infection, which can cause delayed healing and corneal scarring. The infection can be carried into the intraocular tissues by a foreign substance and the bacteria can originate either from sources outside of the eye or from pathogenic organisms already present on the lids, conjunctiva, or in the lacrimal apparatus.

Foreign bodies in the cornea can cause the following problems:

- ➢ *Pain.* Because the cornea is heavily endowed with nerves, an object sitting on the surface of the cornea constantly stimulates the nerves.
- ➢ *Infection.* Bacteria or fungi can be carried by the foreign particle or by fingers used to rub the eye. Such infections

used to be much more common, but antibiotics (and antifungals) have greatly reduced the problem.

➢ *Scarring.* Corneal tissue will heal, but the scars are optically imperfect and may obscure vision.

Intraocular foreign bodies can cause the following problems:

➢ *Infection.* Infection is much less of a problem with low-speed, low-mass particles, but in some cases, the speed of small metallic particles often creates enough heat to sterilize them. Wood particles, however, do not heat up; if they penetrate the eye, they can cause dangerous infection, which usually causes a marked reduction in vision.

➢ *Damage.* Depending on its angle, point of entry, and speed, an intraocular particle may cause traumatic damage to the cornea, iris, lens, or retina. Damage to the lens is especially serious because it is not supplied with blood and is slow to heal. Also, any damage to the lens can act as a catalyst for protein coagulation, resulting in opacity and loss of vision.

Pure copper particles can cause serious damage to the eye because the toxic copper molecules become deposited in the lens, cornea, and iris (chalcosis). Copper alloys do not seem to have any toxic effects.

Pain cannot be relied on to alert the worker that there is a foreign body in his or her eye. The cornea is very sensitive, but if the object has penetrated into the eyeball, there may be no acute pain.

Thermal Burns

Heat can destroy eye and eyelid tissue just as it does any other body tissue, but eye tissues do not recover as well as skin and muscle from such trauma. The lids are more likely to be involved in burns than the eye itself because involuntary closing of the eye is an automatic response to excessive heat.

Irradiation Burns

Nonionizing radiation can be an ocular hazard. Infrared, visible, and ultraviolet light and lasers can present the most significant exposures. Workplace assessments of nonionizing radiation hazards should always include the potential for damage to the eyes, and appropriate engineering controls and protective equipment specified where needed to prevent such injuries. (See Chapter 11, Nonionizing Radiation for more details.)

DAMAGE MECHANISMS

Light in sufficient amounts may damage eye tissue, ranging from barely detectable impairment to gross lesions. The degree of damage depends on the tissue involved and the energy of the incident light photon. Far-infrared light usually effects damage through a general increase in tissue temperature, whereas far-ultraviolet light generally causes specific photochemical reactions.

Damage to lens cells may not be apparent for some time after insult because of the low level of metabolic activity. Low-degree damage is evidenced by vision clouding or cataract and usually is not reversible. When recovery does occur, it is a slow process. Lens damage may be cumulative because dead cells cannot be eliminated from the lens capsule, causing a progressive loss of visual acuity.

Retinal damage can take a number of forms. Generally, the neural components of the retina, such as the photoreceptors, may regenerate when slightly injured, but usually degenerate when extensively injured.

ULTRAVIOLET RADIATION

Harmful exposures to ultraviolet (UV) light usually occur in welding operations, particularly in electric arc welding. The effects include acute keratoconjunctivitis (welder's flash), an acute inflammation of the cornea and conjunctiva which develops in about six hours after even a momentary exposure to the arc light. The welder rarely is involved, being too close to the arc to look at it without an eyeshield, but welders' helpers and other bystanders often suffer from exposure.

INFRARED RADIATION

Unlike UV, infrared (IR) radiation passes easily through the cornea and its energy is absorbed by the lens and retina. With automation of metals operations, eye damage from IR radiation is not as common as it once was.

VISIBLE LIGHT

Various combinations of light sources, exposure duration, and experimental animals have been used to determine the threshold level of light capable of producing a visible retinal lesion. Unfortunately, the experiments recorded were not systematically designed or standardized, leaving numerous gaps and inconsistencies in the reports. Such parameters as pulse duration and irradiated spot area or diameter on the retina are notably lacking. Methods of measurement are often unstated, making comparisons and appraisals of accuracy difficult.

Many models have been proposed to explain the production of visible lesions on the retina from exposure to laser light. Most of the models consider thermal injury to be the only cause of damage. (See Chapter 11, Nonionizing Radiation, for more details.)

Chemical Hazards

The effects of accidental contamination of the eye with chemicals vary from minor irritation to complete loss of vision. In addition to accidental splashing, some mists, vapors, and gases produce eye irritation, either acute or chronic. In some instances, a chemical that does no damage to the eye can be sufficiently absorbed to cause systemic poisoning.

Exposure to irritant chemicals provokes acute inflammation of the cornea (acute keratitis), with pinpoint vacuoles (holes) of the cornea, which rapidly break down into erosions. Some industrial chemicals irritate the mucous mem-

brane, stimulating lacrimation (excessive watering of the eyes). Other results can include discoloration of the conjunctiva, disturbances of vision, double vision from paralysis of the eye muscles, optic atrophy, and temporary or permanent blindness.

Chemical Burns

Because caustics are much more injurious to the eyes than acids, the medical prognosis of caustic burns is always guarded. An eye might not look too bad on the first day after exposure to a caustic, but later it may deteriorate markedly. This is in contrast to acid burns, in which the initial appearance is a good indication of the ultimate damage.

This is because strong acids tend to precipitate a protein barrier that prevents further penetration into the tissue. The alkalis do not do this; they continue to soak into the tissue as long as they are allowed to remain in the eye.

The ultimate result of a chemical burn may be a scar on the cornea. If this is not in front of the window in the iris, vision may not be greatly hampered. If the scar is superficial, a corneal transplant can alleviate burn damage. Densely scarred corneal tissue cannot be repaired by transplants, but plastic implants are now available.

When the chemical penetrates the anterior chamber of the eye, the condition is called iritis (irritation caused by bathing the iris with the chemical agent). Glaucoma may be a complication of chemical iritis.

Evaluating Eye Hazards

It does not take special training or engineering skills to identify most eye hazards. When people handle acids or caustics, when airborne particles of dust, wood, metal, or stone are present, or when blows from blunt objects are likely, eye protection is necessary. Biohazards to hospital and other health care workers also need to be considered.

Workers directly involved with operations producing these hazards are usually included in protective equipment programs, but often workers on the perimeter of eye-hazardous operations are left unprotected, with costly results. Who has not heard of pieces of broken metal tools propelled from the drill press into a worker's eye or flash burns from reflected radiation?

The danger from agents with delayed or cumulative effects is even less likely to be recognized. A host of new technologies carry risk of exposure to a portion of the ultraviolet spectrum: industrial photo processes, sterilization and disinfection, UV therapy and diagnosis in ambulatory medicine and dentistry, polymerization of dental and orthopedic resins, research labs, and insect traps. Nonoccupational exposures from outdoor activities or tanning parlors may enhance borderline exposures in the workplace.

Although work may only occasionally bring an employee near eye hazards, the safest policy is to encourage all-day eye protection. The outdated technique of hanging a pair of community goggles near the grinding wheel is an example of the *eye-hazard job* approach to eye protection, in which jobs that involved eye hazards were identified and eye protection was required only for the worker actually doing the job.

The *eye-hazard area concept* is a better approach. An eye-hazard area is an area where the continuous or intermittent work being performed can cause an eye injury to anyone in the area. The concept emphasizes the need for process and environmental controls such as enclosures and radiation-absorbing surfaces and provides eye protection equipment for workers, neighboring workers, supervisors, and visitors. With proper enforcement and designation of areas, this approach is the most effective way to prevent eye injuries.

First Aid

Propelled object injuries require immediate medical attention. Even for foreign bodies on the corneal surface, self-help should be discouraged; removal of such particles is a job for a trained medical staff member.

Chemical splash injuries require a different approach. Here the extent of permanent damage depends almost entirely on how the victim reacts. If the victim of a concentrated caustic splash gets quickly to an eyewash fountain, properly irrigates the eye for at least 15 minutes, and promptly receives expert medical attention, the chances are good for a clear cornea or, at most, minimal damage.

Such irrigation should be with plain water from standard eyewash fountains, emergency showers, hoses, or any other available sources. Water for eye irrigation should be clean and within certain temperature limits for comfort. Tests show that 112 F (33 C) is about the upper threshold limit for comfort, but colder water, even ice water, apparently causes no harm and is not uncomfortable enough to discourage irrigation.

ANSI Z358.1–1990

The American National Standard Institute (ANSI) standard Z358.1–1990 covers the design and function of eyewash fountains; the water should meet potable standards. It has been noted that acanthamoebae capable of infecting traumatized eyes can be present in potable water. No cases have been directly attributed to the presence of these organisms in eyewash stations, but it seems prudent to follow the ANSI recommendation of a weekly systemic flushing. At least three minutes of flushing significantly reduces the number of organisms.

Portable units are intended for brief irrigation of an injury. A full 15-minute flushing of the injured eye at a stationary station should follow. It has been suggested that water for a portable station be treated with calcium hypochlorite up to 25 ppm free chlorine to eliminate acanthamoebae.

Some industrial medical units use sterile water for irrigation. Use of water substitutes such as neutralizing solutions, boric acid solutions, and mineral oil is discouraged by nearly all industrial ophthalmologists because in many instances, such preparations can cause eye damage greater than if no irrigation were used at all.

PROTECTIVE EQUIPMENT

All eye-protection equipment is designed to enhance one or more of the eye's natural defenses. Chipper's cup goggles extend the bony ridge protecting the eye socket and provide an auxiliary, more penetration-resistant cornea. Chemical splash goggles are better than a blinking eyelid.

There is a tremendous variety of eye protection available, from throwaway visitor's eye shields to trifocal prescription safety spectacles and from welder's helmets to clip-on, antiglare lenses. But the classic safety glasses, with or without sideshields, are probably adequate for 90 percent of general industrial work.

The requirement for proper eye protection should be vigorously enforced to ensure maximum protection for the degree of hazard involved. On certain jobs, 100 percent eye protection must be insisted on.

Protection of the eyes and face from injury by physical and chemical agents or by radiation is vital in any occupational safety program. Eye-protective devices must be considered optical instruments and should be carefully selected, fitted, and used.

Unfortunately, the very term *safety glasses* can be confusing. A Food and Drug Administration (FDA) ruling, effective January 1, 1972, requires that all prescription eyeglass and sunglass lenses be impact-resistant. However, such lenses are not the equivalent of industrial-quality safety lenses and they should not be used in an industrial environment where protection is mandatory.

ANSI Z87.1–1989

Only safety eyewear that meets or exceeds the requirements of ANSI standard Z87.1–1989, *Practice for Occupational and Educational Eye and Face Protection* (referenced in OSHAct Regulations), is approved for full-time use by industrial workers.

The Z87 standard specifies that industrial safety lenses must be at least 3 mm thick and capable of withstanding impact from a 1-in. diameter steel ball dropped 50 in. (1.3 m). The FDA ruling does not mention lens thickness, and requires that a 5/8-in. (16-mm) diameter steel ball be used to verify impact resistance. To pass this test, the lens cannot become chipped or displaced from the frame. For more information, refer to OSHA regulations on eye protection in the general industry codes, in particular, 29 *CFR* 1910.133.

Impact Protection

Three types of equipment are used to protect eyes from flying particles: spectacles with impact-resistant lenses, flexible or cushion-fitting goggles, and chipping goggles.

SPECTACLES

For safety eyewear, polycarbonate lenses are the most impact resistant, and should be considered the lens of choice for industrial environments. In addition, frames must meet the requirements for safety eyewear; an employees personal spectacles (or "dress" frames) would not be considered appropriate eye protection by OSHA in certain occupational environments, even if the lenses were polycarbonate.

Spectacles without sideshields should be used for limited hazards requiring only frontal protection. Where side as well as frontal protection is required, the spectacles must have sideshields. Full-cup sideshields are designed to restrict side entry of flying particles. Semifold or flatfold sideshields can be used where only lateral protection is required. Snap-on and clip-on sideshield types are not acceptable unless they are secured (Figure 5–7). Whether side shields are needed should be determined by the health and safety professional who has evaluated the work environment.

FLEXIBLE-FITTING GOGGLES

These should have a wholly flexible frame forming the lens holder. Cushion-fitting goggles should have a rigid plastic frame with a separate, cushioned surface on the facial contact area (Figure 5–8). Both flexible and cushioned goggles usually have a single plastic lens. These goggles are designed to give the eyes frontal and side protection from flying particles. Most models fit over ordinary ophthalmic spectacles.

CHIPPING GOGGLES

These have contour-shaped rigid plastic eyecups and come in two styles: one for people who do not wear eyeglasses, and one to fit over corrective glasses. Chipping goggles should be used where maximum protection from flying particles is needed.

If lenses will be exposed to pitting from grinding wheel sparks, a transparent and durable coating can be applied to them.

Figure 5–7. Full-cup sideshields are designed to restrict the entry of flying objects from the side of the wearer.

Figure 5–8. Flexible-fitting goggles should have a flexible frame forming the lens holder.

Eye Protection for Welding

In addition to damage from physical and chemical agents, the eyes are subject to the effects of radiant energy. Ultraviolet (UV), visible, and infrared (IR) bands of the spectrum all produce harmful effects on the eyes, and therefore require special attention.

Welding processes emit radiation in three spectral bands. Depending on the flux used and the size and temperature of the pool of melted metal, welding processes emit UV, visible, and IR radiation; the proportion of the energy emitted in the visible range increases as the temperature rises.

All welding presents problems, mostly in the control of IR and visible radiation. Heavy gas welding and cutting operations as well as arc cutting and welding exceeding 30 amperes also emit UV radiation.

Welders can choose the shade of lenses they prefer within one or two shade numbers:

- Shades numbered 1.5–3.0 are intended to protect against glare from snow, ice, and reflecting surfaces and against stray flashes and reflected radiation from nearby cutting and welding operations. These shades also are recommended for use as goggles or spectacles with sideshields worn under helmets in arc-welding operations, particularly gas-shielded arc-welding operations.
- Shade number 4 is the same as shades 1.5–3.0, but for greater radiation intensity.

For welding, cutting, brazing, or soldering operations, the guide for the selection of proper shade numbers of filter lenses or windows is given in ANSI Z87.1–1979, *Eye and Face Protection*. (For more details, see Chapter 11, Nonionizing Radiation.)

Laser Beam Protection

No one type of glass offers protection from all laser wavelengths. Consequently, most laser-using firms do not depend on safety glasses to protect employees' eyes from laser burns. Some point out that laser goggles or glasses might give a false sense of security, tempting the wearer to expose himself or herself to unnecessary hazards (Figure 5–9).

Nevertheless, researchers and laser technicians often need eye protection. Both spectacles and goggles are available and glass for protection against nearly all known lasers can be ordered from eyewear manufacturers. Typically, the eyewear has maximum attenuation at a specific laser wavelength; protection falls off rapidly at other wavelengths. (For more details, see Chapter 11, Nonionizing Radiation.)

Visual Display Terminals (VDTs)

Much concern has focused on health problems associated with the use of VDTs. There is no doubt that use of these

Figure 5–9. One type of safety goggles suitable for protection against laser beams.

devices can cause increased eye fatigue and visual discomfort. Factors that lead to visual discomfort are poor contrast between the characters and background, high contrast between the screen and other surfaces (such as the documents), and glare from and flicker on the screen. Long periods of eye fixation and refractive errors are also significant contributors.

Often, the displays are at a distance of about 30 in. (76 cm) from the operator's eye. Special corrective lenses may be required because the distance is neither near nor far vision.

Regulations for the design and operation of VDT workstations have been issued by some countries, but most authorities oppose rigid rules. Because of the variety of visual problems and work practices of operators, proper design should allow for flexibility in the placement of the screen, keyboard, source documents, and work surfaces. Ambient lighting must be adjustable, bright backgrounds such as windows should be eliminated, and appropriate rest periods are indicated. ANSI/HSF 100–1988 gives detailed recommendations for the design of a visual display terminal workstation. (See Chapter 13, Ergonomics, for additional information.)

Sunglasses

Use of safety sunglasses is a common practice for people who work outdoors, but they are not appropriate for indoor work. Darkly tinted lenses should not be worn indoors unless specifically required because of excessive glare or eye-hazardous radiation. Some computer users feel more comfortable with a light tint on their spectacles; however, to address glare problems, the computer screen itself should be fitted with an anti-glare shield, and the computer situated properly relative to natural and artificial lighting.

PHOTOTROPIC LENSES

Phototropic or photochromic lenses automatically change tint from light to dark and back again, depending on their exposure to UV light. The convenience of sunglasses with variable-tint lenses is obvious, even though such lenses do not react indoors, in a car, or anywhere else that UV light cannot reach.

The ANSI Z87 standard recommends a variety of fixed-density tinted lenses for specific job situations involving radiation harmful to vision. Each tint is assigned an individual shade number, which is inscribed on the front surface of each such lens. The current Z87 standard makes no mention of phototropic lenses; this fact alone should give pause to health and safety specialists who might be pressured to shift a work force immediately into phototropic lenses.

Such lenses may have a future for outdoor use by telephone line and brush crews and gas-line transmission workers. However, until safety eyewear manufacturers are willing—or able—to certify phototropic lenses as being fully in compliance with the Z87 standard, industry would be well-advised to follow ANSI guidelines.

Contact Lenses

Contact lenses have had a history of being banned in industrial environments. However, there is little (to no) evidence that across-the-board prohibition of their use is warranted. In May 1998, the Contact Lens Section of the American Optometric Association issued revised "Guidelines For The Use of Contact Lenses in Industrial Environments." In this, they stated that "Contact lenses may be worn in some hazardous environments with appropriate covering safety eyewear. Contact lenses of themselves do not provide eye protection in the industrial sense." Contact lenses should not be considered eye protection and are not intended as such. However, if eye protection appropriate for the job being done is worn over the contact lenses, employees should be able to safely use them. There are certain eye conditions, such as keratoconus, where an individual's vision may be significantly decreased by wearing glasses instead of contact lenses; in this situation, a greater hazard may be produced by insisting on the wearing of glasses.

Health and safety practitioners often have banned the use of contact lenses with respiratory protection. Lawrence Livermore National Laboratory conducted a study of contact lens wearers who used self-contained breathing apparatus, and found no adverse effects to the eyes. Some state OSHA plans may still prohibit the use of contact lenses with respiratory protection; health and safety professionals are advised to consult the applicable regulations.

Because each workplace presents its own unique hazards, the health and safety professional should assess and make the ultimate decision as to the use of contact lenses.

Employees must not insert or remove contact lenses in hazardous environments. In the event of a chemical splash to

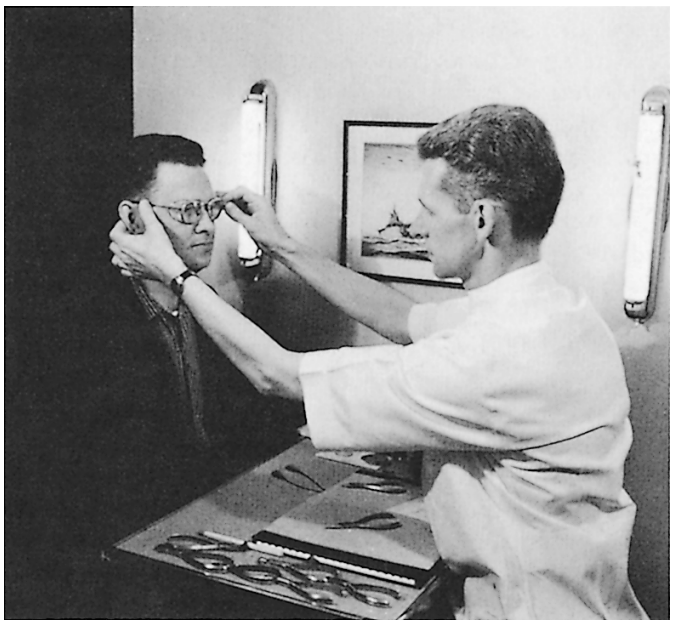

Figure 5–10. Safety glasses should be properly fitted and adjusted.

the eyes, the person should start irrigating the eyes while still wearing the contacts, and remove them while irrigating (often the pressure of the water will force them out of the eyes).

Comfort and Fit

To be comfortable, eye-protective equipment must be properly fitted. Corrective spectacles should be fitted only by a qualified, licensed practitioner. However, a technician can be trained to fit, adjust, and maintain eye-protective equipment. Of course, each worker should be taught the proper care of the device being used.

To give the widest possible field of vision, goggles should be close to the eyes but the eyelashes should not touch the lenses (Figure 5–10).

Various defogging materials are available. Before a selection is made, test to determine the most effective type for a specific application.

In areas where goggles or other types of eye protection are extensively used, goggle-cleaning stations should be conveniently located, along with defogging materials, wiping tissues, and a waste receptacle.

VISION CONSERVATION PROGRAM

There are four steps in a vision conservation program:

1. The environmental survey
2. Vision screening program
3. Remedial program
4. Professional fitting and follow-up procedures

Environmental Survey

The environment should be surveyed by people qualified in occupational health and safety. The survey should assess the likelihood of injury and potential severity of injury from the worker's job operation, the potential for injury from adjacent operations, and the optimum visual acuity requirements for fast, safe, efficient operations.

The environmental survey includes illumination measurements and recommendations for improvements to make the workplace safer. Often, simply cleaning existing lighting can increase illumination 100 percent.

Job working distances and viewing angles should be measured so eye doctors have the necessary information to prescribe lens strengths affording optimum comfort, efficiency, safety, and ergonomic advantage (Figure 5–11).

Each workstation should be free of toxic or corrosive materials and employees should be instructed in the correct use of eyewash facilities. Eyewash fountains should be examined to make certain they work properly and provide an even flow of water.

All environmental factors influencing an employee's visual performance and safety should be written in a visual job description, in terms understandable to the eye doctors who will care for employees with deficient vision.

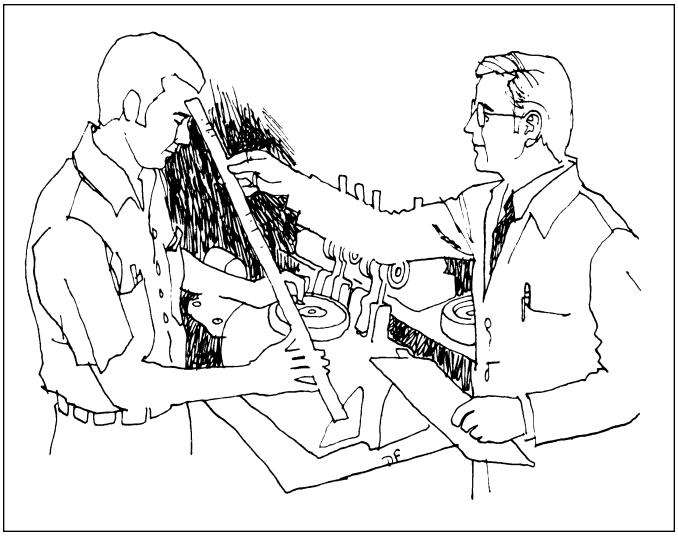

Figure 5–11. Measuring the distance from the eye to the work plane is essential for proper safety vision prescriptions.

Vision Screening Program

The next step, after working conditions and visual requirements are known, is to determine the visual status of the work force. Reliable vision screening instruments are available for use by nurses or trained technicians.

These instruments test the visual acuity in each eye separately, both eyes together, both at near point (usually working distance), both at far point (distant vision), and binocular coordination (the ability to make the two eyes work together). Additional specific tests—such as color vision, field of vision, glaucoma testing, and depth perception—can be added when a need is indicated.

Often, an employee actually performs many jobs. In these instances, recommendations are made after the job most frequently performed is compared with the one most visually demanding.

Remedial Program

Each employee is told the result of his or her vision screening; people showing deficiencies are referred to the eye doctor of their choice. The employee goes to the doctor with the prescription form for safety glasses and a written description of the visual aspect of the job or duties at work. The job description includes recommendations concerning the type of prescription that will make the worker more comfortable and more efficient.

Professional Fitting

The final step in a vision conservation program is professionally fitting the protective and corrective safety eyewear to the employee. Proper fitting and sizing are essential and cannot be correctly done by the tool crib attendant or purchasing agent. Workers come in various sizes and shapes, as do safety glasses. Proper measurement and fitting can be the difference between a successful and an unsuccessful program. A

perfect prescription is useless if the frame hurts so much that it cannot be worn.

This fitting procedure is equally important for employees required to wear nonprescription safety glasses. These employees usually are the most difficult to fit. They are not accustomed to having anything in front of their eyes or feeling weight on their nose or ears. Considerable care must be exercised in the fitting for such employees. Adjustment and alignment should be readily available.

Human vision is not static; it changes constantly. Employees, especially those over age 40, should be advised that gradual, sometimes unnoticed, changes in their vision may affect their safety and efficiency.

Continued testing must be instituted as a health and safety department policy. If no health specialist is employed at the facility, make arrangements for this service with your local health care community. The local academy of ophthalmology or optometry can usually provide trained personnel.

Guidelines

The following guidelines should be a part of every vision conservation program:

- ➢ Make it a 100-percent program; include everyone. Employees will accept it more readily and it will be easier to administer. Promote it well in advance; get union cooperation.
- ➢ Make certain that safety eyewear is properly fitted. A few jobs (welding, labs, lasers) require special types. Optical companies will assist in fitting eyewear and explaining maintenance.
- ➢ Include eye-care stations for first aid and for cleaning lenses.
- ➢ Control eye hazards at the source; install safety glass guards on machines to prevent flying chips or splashing liquids and install enclosures to control fine dusts, mists, or vapors.
- ➢ Make sure all areas have adequate lighting, are free from glare, and are painted in colors that emphasize depth perception and highlight potential hazards.
- ➢ Post signs such as ALL PERSONNEL AND VISITORS MUST WEAR PROTECTIVE EYEWEAR in all hazardous areas.
- ➢ All employees should be given preplacement eye examinations. Periodic follow-up examinations should be scheduled, especially for employees over 40 years of age.

AMA *GUIDES TO THE EVALUATION OF PERMANENT IMPAIRMENT*

This section is adapted from the AMA's *Guides to the Evaluation of Permanent Impairment,* 5th edition. It is included in this chapter to assist health and safety professionals in interpreting and understanding medical reports of workers' compensation cases.

This guide provides a method for determining permanent visual impairment and its effects on a person's ability to perform the activities of daily living. The guide focuses on functional impairment of the visual system as a whole. The fifth edition of the AMA guide, published in 2000, was revised substantially from the fourth edition. They used the consensus document, *Guide to the Evaluation of Visual Impairment,* developed by the International Society for Low Vision Research and Rehabilitation.

A *permanent visual impairment* is defined as a permanent loss of vision that remains after maximal improvement of the underlying conditions has been reached. Measurement of both visual acuity and visual field are obtained, and numerical assessments of these functions are used to derive an estimate of their effect on functional vision—the ability to perform generic activities of daily living.

The guide uses a *Functional Vision Score* (FVS), which is based on an assessment of visual acuity and visual field. *Visual acuity* is described as the ability of the eye to perceive details. *Visual field* refers to the ability to detect objects in the periphery of the visual environment. (See Table 5–A.)

Another important visual function is *contrast sensitivity,* which refers to the ability to detect larger objects of poor contrast. In addition, the guides allow for individual adjustments for other defects such as glare sensitivity, color vision, binocularity, stereopsis, suppression, and diplopia. If these deficits cause a significant loss that is not reflected in a visual acuity or visual field loss, they may be used to adjust the impairment rating.

Clinical Evaluation of Vision Loss

To accurately assess visual impairment, the clinician needs to perform a thorough visual exam, which includes the cause, severity, and prognosis of the underlying disorder and the expected or documented effects of the vision loss on the ability to perform activities of daily living. The assessment should include the following:

- ➢ Medical history with an emphasis on preexisting conditions, treatments, and the major cause of the current vision loss.
- ➢ Current condition of the eyes and visual system, with documentation of anatomic findings.
- ➢ Visual acuity measurements with best correction, binocularity, and for each eye separately.
- ➢ Visual field measurement for each eye.
- ➢ Other visual functions such as contrast sensitivity or color vision.
- ➢ Calculation of an initial impairment rating.
- ➢ Other factors that may affect the individual's ability to perform activities of daily living.
- ➢ Discussion of factors that may cause an adjustment of the initial ability estimate.

The required equipment to perform these tests includes a standardized letter chart, standardized reading tests, visual field equipment, and other tests such as contrast sensitivity tests and glare tests.

Calculating the Visual Impairment Rating

The recommended methods to calculate visual impairment is given in the following (also see Table 5–A):

1. Measure visual acuity and convert to a Visual Acuity Score (VAS). (Table 5–B)
2. Combine acuity scores and use table to determine a Functional Acuity Score (FAS). (Tables 5–C and 5–D)
3. Measure visual fields and convert each to a Visual Field Score (VFS). (Table 5–E)
4. Use table to combine both eyes to obtain a Functional Field Score (FFS). (Table 5–F)
5. Use rules to combine functional acuity score and functional field score to a Functional Vision Score (FVS) (Table 5–A).
6. Subtract the functional vision score from 100 to obtain the impairment rating for the visual system.

If additional visual impairments are not reflected in the reductions of visual acuity or visual field the examiner may make adjustments as described in the section 12.4—Impairment of the Visual System, pages 296–300 in the AMA *Guides to the Evaluation of Permanent Impairment,* 5th edition (see Bibliography). Table 5–D gives classifications of Visual Acuity Impairment (assuming normal visual fields) and Table 5–G gives classification of Visual Field Impairment (assuming normal visual acuity).

For more complete information of assessing visual impairment consult Chapter 12 in the AMA's *Guide to the Evaluation of Permanent Impairment,* 5th ed.

SUMMARY

Ocular anatomy, visual performance, disorders, and problems were discussed. Also covered were potential hazards and how to protect and conserve vision, as well as how to evaluate visual impairment using the fifth edition of the AMA *Guides to the Evaluation of Permanent Impairment.*

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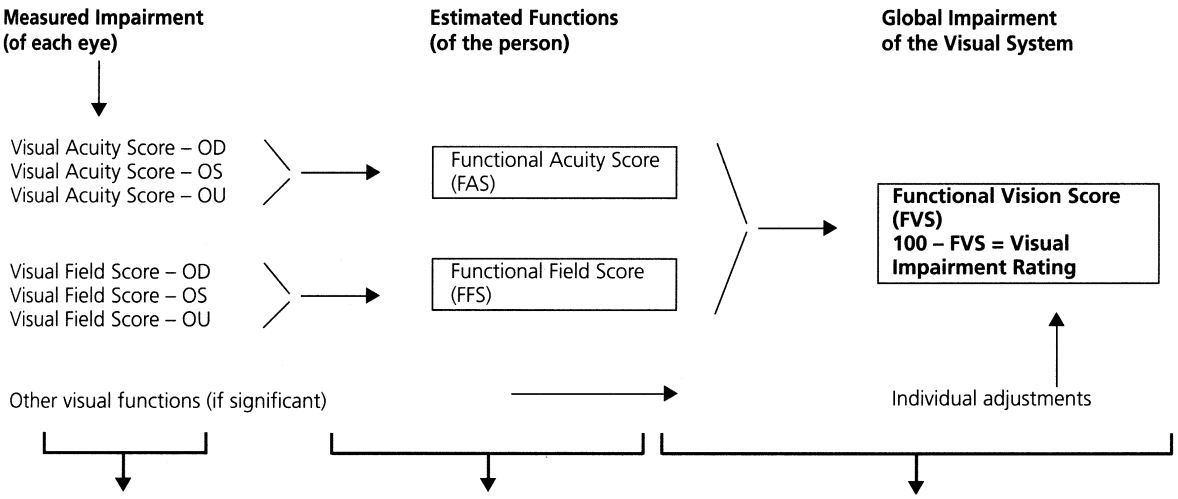
Table 5–A. *Calculation of the Impairment Rating for the Visual System*



1. Use Table 12-2 to convert each of the measured acuity values to a *Visual Acuity Score.*
3. Use Table 12-5 or the rules in Section 12.3c to convert each of the measured field values to determine a *Visual Field Score.*
2. Use Table 12-3 to combine the acuity scores from each eye to determine a single *Functional Acuity Score.*
4. Use Table 12-6 to combine the field scores from each eye to determine a single *Functional Field Score.*
5. Use the rules in Section 12.4 to combine the Functional Acuity Score and the Functional Field Score to determine the *Functional Vision Score.*
6. Make adjustments for other visual function deficits, if significant.
7. Use Table 12-10 to adjust to a whole person impairment.

Note that the prefix *visual* is used when the score refers to each eye. The prefix *functional* refers to the estimated performance of the individual. The term vision *score* combines visual acuity and visual field estimates (and individual adjustments, if significant). Source: *Evaluation of Permanent Impairment*, 5th ed. American Medical Association, copyright 2000.

Table 5–B. ***Impairment of Visual Acuity****

Impairment Classes (Based on *ICD-9-CM*)		Visual Acuity		Visual Acuity Score (ability)	Visual Acuity Impairment Rating (%) (ability loss)	Estimated Reading Ability
		US Notation	1 m Notation			
(Near-) Normal Vision	Range of Normal Vision	20/12.5 20/16 20/20 20/25	1/0.63 1/0.8 1/1 1/1.25	110 105 100 95	... ... 0 5	Normal reading speed Normal reading distance Reserve capacity for small print
	Near-Normal Vision	20/32 20/40 20/50 20/63	1/1.6 1/2 1/2.5 1/3.2	90 85 80 75	10 15 20 25	Normal reading speed Reduced reading distance No reserve for small print
Low Vision	Moderate Low Vision	20/80 20/100 20/125 20/160	1/4 1/5 1/6.3 1/8	70 65 60 55	30 35 40 45	Near-normal with reading aids Uses low-power magnifier or large-print books
	Severe Low Vision	20/200 20/250 20/320 20/400	1/10 1/12.5 1/16 1/20	50 45 40 35	50 55 60 65	Slower than normal with reading aids Uses high-power magnifiers
	Profound Low Vision	20/500 20/630 20/800 20/1000	1/25 1/32 1/40 1/50	30 25 20 15	70 75 80 85	Marginal with reading aids Uses magnifiers for spot reading but may prefer talking books
(Near-) Blindness	Near-Blindness	20/1250 20/1600 20/2000 or less	1/63 1/80 1/100 or less	10 5	90 95	No visual reading Must rely on talking books, Braille, or other nonvisual sources
	Total Blindness	No light perception		0	100	

* Use this table to determine a Visual Acuity Score for each eye. Proceed to Table 12-3 to combine the scores from each eye to a single Functional Acuity Score. Note: The visual acuity values used in this table follow a strict geometric progression. For clinical use, values such as 20/32 and 20/63 may be rounded to 20/30 and 20/60. Source: *Evaluation of Permanent Impairment*, 5th ed. American Medical Association, copyright 2000.

Table 5–C. ***Calculation of the Acuity-Related Impairment Rating****

Measured Snellen Values		**Calculated Visual Acuity Scores**
OU: letter chart acuity: 20/____	→	VAS_{OU}: _____ × 3 = ____
OD: letter chart acuity: 20/____	→	VAS_{OD}: _____ × 1 = ____
OS: letter chart acuity: 20/____	→	VAS_{OS}: _____ × 1 = ____
Add OU, OD, and OS		= ____
Divide by 5 to calculate the weighted average		= ____ = Functional Acuity Score (FAS)
Acuity-Related Impairment Rating = 100 – FAS		= ____

Optionally, calculate a Visual Acuity Score for reading (near) acuity. If the outcome is significantly different from the letter chart acuity score, document the differences and calculate the average:

$$\mathbf{FAS_{global} = (FAS_{letter\ chart} + FAS_{reading})/2}$$

* If visual fields are normal and no individual adjustments are made, the acuity-related impairment rating equals the whole person impairment rating. Source: *Evaluation of Permanent Impairment*, 5th ed. American Medical Association, copyright 2000.

Table 5–D. ***Classification of Visual Acuity Impairment****

Class 1 0%-9% Impairment of Visual Acuity	**Class 2 10%-29% Impairment of Visual Acuity**	**Class 3 30%-49% Impairment of Visual Acuity**	**Class 4 50%-69% Impairment of Visual Acuity**	**Class 5 70%-89% Impairment of Visual Acuity**	**Class 6 90%-100% Impairment of Visual Acuity**
FAS: ≥ 91	FAS: 90-71	FAS: 70-51	FAS: 50-31	FAS: 30–11	FAS: ≤ 10
Range of normal vision	Near-normal vision (mild vision loss)	Moderate vision loss	Severe vision loss	Profound vision loss	(Near-) Total vision loss
Both eyes have visual acuity of 20/25 or better	Both eyes have visual acuity of 20/60 or better	Both eyes have visual acuity of 20/160 or better	Both eyes have visual acuity of 20/400 or better	Both eyes have visual acuity of 20/1000 or better	Both eyes have visual acuity worse than 20/1000
	One eye has 20/200 or less; the other eye is normal	One eye has 20/200 or less; the other eye has 20/80	One eye has 20/200 or less; the other eye has 20/200		

*This table assumes that the visual fields are normal and provides general impairment ranges for the listed conditions. Use Tables 12-2 and 12-3 to calculate a more exact impairment rating and to handle cases of visual acuity loss that are not listed. Proceed to Tables 12-5 and 12-6 if visual field loss is present. Source: *Evaluation of Permanent Impairment,* 5th ed. American Medical Association, copyright 2000.

Table 5–E. ***Impairment of the Visual Field****

Impairment Classes (Based on *ICD-9-CM*)		**Special Conditions**	**Average Radius If Loss Is Concentric**	**Visual Field Score (ability)**	**Visual Field Impairment Rating (%) (ability loss)**	**Estimated Ability for Visual Orientation and Mobility (O + M) Tasks**
(Near-) Normal Vision	Range of Normal Vision		 60°	110 105 100 95	… … 0 5	Normal visual orientation Normal mobility skills
	Near-Normal Vision	 Loss of 1 eye	50° 40°	90 85 80 75	10 15 20 25	Normal O + M performance Needs more scanning Occasionally surprised by events on the side
Low Vision	Moderate Low Vision	 Lost upper field	30° 20°	70 65 60 55	30 35 40 45	Near-normal performance Requires scanning for obstacles
	Severe Low Vision	Hemianopia Lost lower field	10° 8°	50 45 40 35	50 55 60 65	Visual mobility is slower than normal Requires continous scanning May use cane as adjunct
	Profound Low Vision		6° 4°	30 25 20 15	70 75 80 85	Must use long cane for detection of obstacles May use vision as adjunct for identification
(Near-) Blindness	Near-Blindness		2° or less 0°	10 5	90 95	Visual orientation unreliable Must rely on long cane, sound, guide dog, and other blind mobility skills
	Total Blindness	No visual fields		0	100	

* This table follows the clinical usage of describing filed losses on the basis of the remaining radius. In the rehabilitation and disability literature, filed losses are often described on the basis of the remaining diameter (eg, a concentric field loss to a radius of 10° leaves a field with a diameter of 20°). Source: *Evaluation of Permanent Impairment,* 5th ed. American Medical Association, copyright 2000.

Table 5–F. ***Calculation of the Field-Related Impairment Rating***

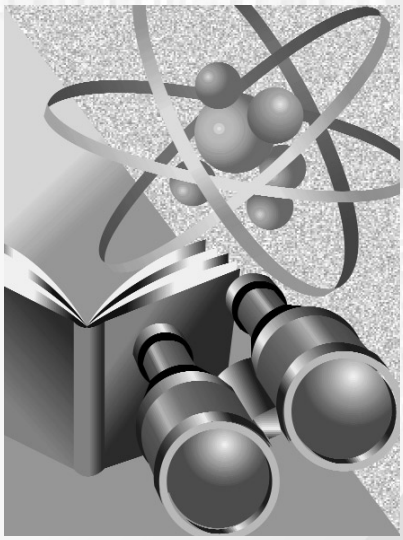
Measured Field Plots		Calculated Visual Field Scores
Binocular field plot (OU)	→	VFS_{OU}: _____ × 3 = ____
Field plot right eye (OD)	→	VFS_{OD}: _____ × 1 = ____
Field plot left eye (OS)	→	VFS_{OD}: _____ × 1 = ____
Add OU, OD, and OS		= ____
Divide by 5 to calculate the weighted average		= ____ = Functional Field Score (FFS)
Field-related Impairment Rating = 100 – FFS		= ____

Source: *Evaluation of Permanent Impairment,* 5th ed. American Medical Association, copyright 2000.

Table 5–G. ***Classification of Visual Field Impairment****

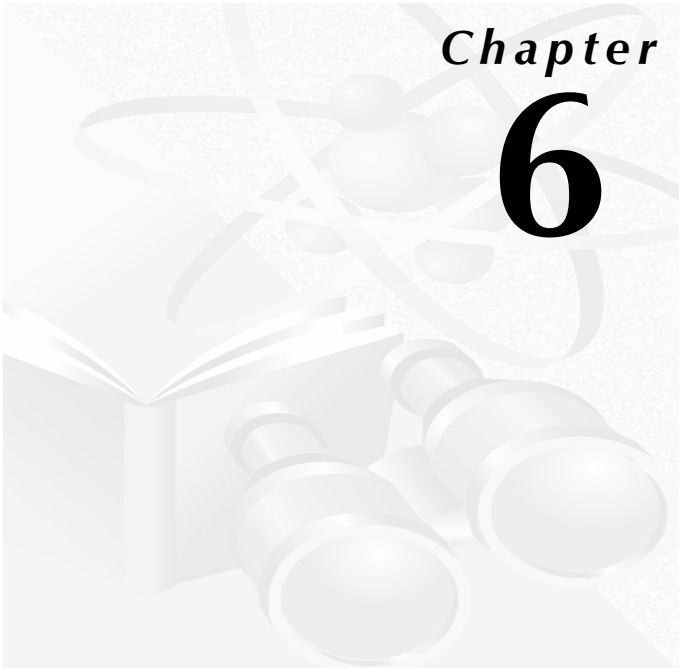
Class 1 0%-9% Impairment of Visual Field	**Class 2 10%-29% Impairment of Visual Field**	**Class 3 30%-49% Impairment of Visual Field**	**Class 4 50%-69% Impairment of Visual Field**	**Class 5 70%-89% Impairment of Visual Field**	**Class 6 90%-100% Impairment of Visual Field**
FFS: ≥ 91	FFS: 90-71	FFS: 70-51	FFS: 50-31	FFS: 30–11	FFS: ≤ 10
Range of normal vision	Near-normal vision (mild vision loss)	Moderate vision loss	Severe vision loss	Profound vision loss	(Near-) Total vision loss
Both eyes have visual fields > 50°	Both eyes have visual fields ≤ 50° and > 30°	Both eyes have visual fields ≤ 30° and > 10°	Both eyes have visual fields ≤ 10° and > 6°	Both eyes have visual fields ≤ 6° and > 2°	Both eyes have visual fields of 2° or less
	One eye is lost (the other eye is normal)	Both eyes have lost the upper half-field	Both eyes have lost the lower half-field Homonymous hemianopia		

* This table assumes that the visual acuity is still normal. It can be used to determine the general impairment range for the listed conditions. Use Tables 12-5 and 12-6 or the detailed rules in Section 12.3c to calculate a more exact figure and to handle other visual field loss. Use Tables 12-2 and 12-3 if visual acuity loss is present.
Source: *Evaluation of Permanent Impairment,* 5th ed. American Medical Association, copyright 2000.



Recognition of Hazards

Part III



Chapter 6

Industrial Toxicology

by Richard Cohen, MD, MPH

Toxicology is the science that studies the harmful, or toxic, properties of substances. We are exposed daily to a variety of substances which are not hazardous under usual circumstances. However, any substance contacting or entering the body is injurious at some excessive level of exposure and theoretically can be tolerated without harmful effect at some lower exposure.

DEFINITION

A *toxic effect* is any reversible or irreversible harmful effect on the body as a result of contact with a substance via the respiratory tract, skin, eye, mouth, or other route. Toxic effects are undesirable disturbances of physiological function caused by an overexposure to chemical or physical agents. They also arise as side effects in response to medication and vaccines. Toxicity is the capacity of a chemical to harm or injure a living organism. Toxicity entails the dimension of *quantity* or *dose;* the toxicity of a chemical depends on the degree of exposure and absorption.

Many chemicals essential for health in small quantities are highly toxic in larger quantities. Small amounts of zinc, manganese, copper, molybdenum, selenium, chromium, nickel, tin, potassium, and many other chemicals are essential for life. However, severe acute and chronic toxicity may result from an uptake of large amounts of these materials. For example, nickel and chromium in some of their forms are considered carcinogens.

The responsibility of the industrial toxicologist is to define how much is too much and to prescribe precautionary measures and limitations so that usual or recommended use does not result in the absorption of too much of a particular substance. From a toxicological viewpoint, the industrial hygienist must consider all types of exposure and the subsequent effects on the living organism.

Toxicity Versus Hazard

Toxicity and hazard differ. Toxicologists consider toxicity as the ability of a substance to produce an unwanted effect when the substance has reached a sufficient concentration at a certain site in the body; hazard is regarded as the probability that this concentration will occur at that site. Many factors contribute to determining the degree of hazard—route of entry, quantity of exposure, physiological state, environmental variables, and other factors. Assessing a hazard involves estimating the probability that a substance will cause harm. Toxicity, along with the chemical and physical properties of a substance, determines the level or degree of hazard. Two liquids can possess the same degree of toxicity but present different degrees of hazard. One may be odorless and not irritating to the eyes and nose whereas the other may produce a pungent or disagreeable odor at a harmless concentration. The material with the warning properties at harmless concentrations may present a lesser degree of hazard; its presence can be detected in time to avert injury.

Some chemical agents are not selective in their action on tissues or cells; they can exert a harmful effect on all living matter. Other chemical agents act only on specific cells. Some agents are harmful only to certain species; other species have built-in protective mechanisms.

The term *toxicity* is commonly used in comparing one chemical agent with another but is meaningless without data designating the biological species used and the conditions under which the harmful effects were induced.

A chemical stimulus can be considered to have produced a toxic effect when it satisfies the following criteria:

- An observable or measurable physiological deviation has been produced in any organ or organ system. The change can be anatomic in character and may accelerate or inhibit a normal physiological process, or the deviation can be a specific biochemical change.
- The observed change can be duplicated from animal to animal even though the dose-effect relationships vary.
- The stimulus has changed normal physiological processes in such a way that a protective mechanism is impaired in its defense against other adverse stimuli.
- The effect is either reversible or at least attenuated when the stimulus is removed.
- The effect does not occur without a stimulus or occurs so infrequently that it indicates generalized or nonspecific response. When high degrees of susceptibility are noted, equally significant degrees of resistance should be apparent.
- The observation must be noted and must be reproducible by other investigators.
- The physiological change reduces the efficiency of an organ or function and impairs physiological reserve in such a way as to interfere with the ability to resist or adapt to other normal stimuli, either permanently or temporarily.

Though the toxic effects of many substances used in industry are well known, the toxicity of others is not yet well defined. Although certain important analogies are apparent between structure and toxicity, important differences exist that require individual study of each compound.

In addition to establishing toxicity, evaluation of a chemical hazard involves establishing the amount and duration of exposure, the physical characteristics of the substance, the conditions under which exposure occurs, and the determination of the effects of other substances in a combined exposure. All of these may significantly influence the toxic potency of a substance.

The chemical properties of a compound are often one of the main factors in its hazard potential. Vapor pressure (an indicator of how quickly a liquid or solid evaporates) partially determines whether a substance has the potential to pose a hazard from inhalation. Many solvents are quite volatile and vaporize readily into the air to produce high concentrations of vapor. Hence, a solvent with a low boiling point would be a greater hazard than an equally toxic solvent with a high boiling point simply because it is more volatile and it evaporates faster.

Chemical injury can be local or systemic, and the toxicological reactions can be slight or severe. Local injury results from direct contact of the irritant with tissue. The skin can be severely burned or the surface of the eye can be injured to the extent that vision is impaired. In the respiratory tract, the lining of the trachea and the lungs can be injured as a result of inhaling toxic amounts of vapors, fumes, dusts, or mists.

ENTRY INTO THE BODY

In discussing toxicity, it is necessary to know how a substance enters the body and, if relevant, the bloodstream. For an adverse effect to occur, the toxic substance must first reach the organ or bodily site where it causes damage. Common "routes of entry" are inhalation, skin absorption, ingestion, and injection. Depending on the substance and its specific properties, however, entry (absorption) can occur by more than one route, such as inhaling a solvent that can also penetrate the skin.

Inhalation

For industrial exposures, a major, if not predominant route of entry is inhalation. Any airborne substance can be inhaled.

The respiratory system is composed of two main areas: the upper respiratory tract airways (the nose, throat, trachea, and major bronchial tubes leading to the lobes of the lungs) and the alveoli, where the actual transfer of gases across thin cell walls takes place. For particles, only those smaller than about 5 μm in diameter are likely to enter the alveolar sac.

The total amount of a toxic compound absorbed via the respiratory pathways depends on its concentration in the air, the duration of exposure, and the pulmonary ventilation volumes, which increase with higher work loads. If the toxic substance is present in the form of an aerosol, deposition

and absorption occur in the respiratory tract. For more details, see Chapter 2, The Lungs.

Gases and vapors of low water solubility but high fat solubility pass through the alveolar lining into the bloodstream and are distributed to organ sites for which they have special affinity. During inhalation exposure at a uniform level, the absorption of the compound into the blood reaches an equilibrium with metabolism and elimination.

Skin Absorption

An important route of entry for some chemicals is absorption through skin. Contact of a substance with skin results in these four possible actions:

- ➢ The skin can act as an effective barrier
- ➢ The substance can react with the skin and cause local irritation or tissue destruction
- ➢ The substance can produce skin sensitization
- ➢ The substance can penetrate skin to reach the blood vessels under the skin and enter the bloodstream

For some substances (such as parathion), the skin has been the main portal of entry in many toxic occupational exposures. For other substances (such as aniline, nitrobenzene, and phenol), the amounts absorbed through the skin are roughly equivalent to the amounts absorbed through inhalation. For the majority of other organic chemicals, the contribution from skin (cutaneous) absorption to the total amount absorbed is significant. Hence, toxic effects can occur because of cutaneous penetration.

The cutaneous absorption rate of some organic chemicals rises when temperature and perspiration increase. Therefore, absorption can be higher in warm climates or seasons. The absorption of liquid organic chemicals may follow surface contamination of the skin or clothes; for other compounds, it may directly follow the vapor phase, in which case the rate of absorption is roughly proportional to the air concentration of the vapors. The process involves a combination of deposition of the substances on the skin surface followed by absorption through the skin.

The physicochemical properties of a substance determine absorption potential through intact skin. Among the important factors are skin pH and the chemical's extent of ionization, aqueous and lipid solubilities, and molecular size.

Human skin shows great differences in absorption at different anatomic regions, primarily due to differences in thickness. The skin on the palm of the hand has approximately the same penetration potential as that of the forearm for certain organic phosphates. The skin on the back of the hand and the skin of the abdomen have twice the penetration potential of the forearm, whereas follicle-rich sites such as the scalp, forehead, and scrotum show a much greater penetration potential. High temperatures generally increase skin absorption by increasing vasodilation and sweating. If the skin is damaged by abrasion dermatitis, the normal protective barrier to absorption of chemicals is lessened and penetration occurs more easily. (See Chapter 3, The Skin, for more information.)

Ingestion

The problem of ingesting chemicals is not widespread in industry; most workers do not deliberately swallow materials they handle. Nevertheless, workers can ingest toxic materials as a result of eating in contaminated work areas; contaminated fingers and hands can lead to accidental oral intake when a worker eats or smokes on the job. They can also inhale materials when contaminants deposited in the respiratory tract are carried out to the throat by the action of the ciliated lining of the respiratory tract. These contaminants are then swallowed and significant absorption of the material may occur through the gastrointestinal tract. Approximately one quart of mucus is produced daily in an adult's lungs. This constant flow of mucus can carry contaminants out of the lungs into the throat to be swallowed with the saliva or coughed up and expectorated.

Toxicity after ingestion is generally lower than the inhalation toxicity for the same dose and substance because absorption of many substances across the intestinal wall and into the bloodstream is relatively poor. Food and liquid mixed with a toxic substance not only provide dilution, but can combine with it to form less soluble substances. Also, action of digestive acids and enzymes can chemically alter the substance and reduce its toxicity. After absorption via any route into the bloodstream, the substance may enter the liver, which metabolically alters, degrades, or detoxifies many substances. This detoxification process is an important body defense mechanism. Basically, detoxification involves chemical reactions, which in some cases change the substance to a less toxic or more water-soluble compound.

Injection

Although infrequent in industry, a substance can be injected into some part of the body. This can be done directly into the bloodstream, peritoneal cavity, pleural cavity, skin, muscle, or any other place a needle or high-pressure orifice can reach. The effects produced vary with the location of administration. In industrial settings, injection is an infrequent route of worker chemical exposure.

There is increasing attention to prevention of skin puncture and injection injuries associated with bloodborne pathogens (hepatitis B, HIV, and hepatitis C). Risk of infection is significant following accidental skin puncture by a needle or instrument contaminated with infected blood or tissue.

In the laboratory, toxic substances are injected into animals because it is far more convenient and less costly than establishing blood levels by inhalation or skin exposures. Intravenous injection sidesteps protective mechanisms in the body that prevent substances from entering the blood.

DOSE–RESPONSE RELATIONSHIP

A fundamental consideration in toxicology is the *dose–response relationship*. In animal studies, a dose is administered

to test animals and increased or decreased until a range is found where at the upper end all animals show a preselected health effect (e.g., death, injury) and, at the lower end, all animals are absent the health effect. The data collected are used to prepare a dose-response curve relating health effect incidence to dose administered (Figure 6–1).

The doses given are expressed as the quantity administered per unit body weight, quantity per skin surface area, or quantity per unit volume of respired air. In addition, the length of time during which the dose was administered should be listed.

The dose–response relationship can also be expressed as the product of a concentration (C) multiplied by the time duration (T) of exposure. This product is proportional more or less to a constant (K); or mathematically, $C \times T \approx K$. The dose involves two variables—concentration and duration of exposure. For certain chemicals, a high concentration breathed for a short time produces the same effect as a lower concentration breathed for a longer time. The CT value provides a rough approximation of other combinations of concentration of a chemical and time that would produce similar effects. Although this concept must be used very cautiously and cannot be applied at extreme conditions of concentration or time, it can be useful in predicting safe limits for some airborne contaminants in the workplace. Regulatory exposure limits are set so that the combination of concentrations and time durations are theoretically below the levels that produce injury to exposed individuals.

Threshold Concept

For most chemicals there is a *threshold of effect* or a *no-effect level.* The most toxic chemical known, if present in small enough amounts, produces no measurable effect. It may damage one cell or several cells, but no measurable effect, such as kidney dysfunction, will result. As the dose is increased, there is a point at which the first measurable effect is noted or at which the incidence of a health effect in the exposed population exceeds its incidence in unexposed populations. The (toxic) potency of a chemical is defined by the relationship between the dose (amount) of the chemical and the response produced in a biological system. A high concentration of toxic substance in the target organ causes a severe reaction and a low concentration causes a less severe or no reaction.

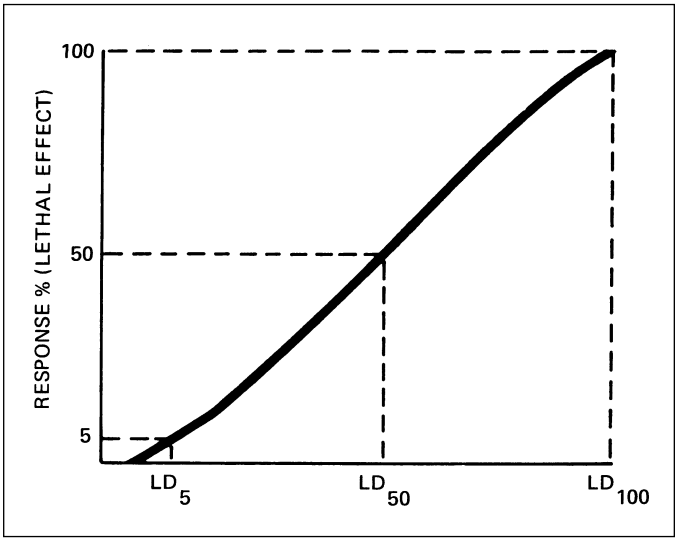


Figure 6–1. Dose-response curves for a chemical agent administered to a uniform population of test animals. (LD=lethal dose; number shown after LD indicates the percent of exposed animals that are affected. LD_{50} means that dose given at which 50 percent of exposed animals died.)

The word *toxic* relates to the dose or amount of a substance necessary to cause injury, illness, or significant adverse health effect. If that dose is low compared to the harmful dose for other substances, it is described as more "toxic." In other words, although all substances produce harmful effects at some dose, a toxic substance causes harmful effects at low doses.

Although most exposures in industry occur by way of the respiratory tract or skin, most published dose-response data are found in studies of experimental animals. In these experiments, the test substances were usually administered by mouth (in food, in drinking water, or by intubation [tube] directly into the stomach) or injection (intravenous, intramuscular, intraperitoneal, etc.).

The harmfulness of a material depends on its chemical composition, the type and rate or level of exposure, and the fate of the material in the body. For many substances, a single large dose of a toxic substance produces a greater response than the same total dose administered in small amounts over a long period of time. Each of the small amounts can be detoxified quickly but a large dose produces its detrimental action before appreciable detoxification occurs. If a substance is detoxified or excreted at a rate slower than the rate of intake, it may cause continuing (cumulative) effects.

Accumulation of a substance in the body is understood as a process in which the level of the substance increases with the duration of exposure and can apply to both continuous and repeated exposure. Biological tests of exposure show that an accumulation is taking place when rising levels of the substance are seen in the urine, blood, or expired air (Figure 6–2).

Exposure thresholds are most easily determined (and more available) for effects occurring soon after exposure. Other effects such as reproductive defects and cancer occur months or years after exposure began. Dose-related data are often imprecise in human epidemiological studies. For these and other reasons, thresholds for some carcinogens (such as asbestos) have not been identified and are considered to be zero.

Because different biological mechanisms are involved in reproductive toxicity, attempts are being made to identify exposure levels (mostly from animal studies) below which no

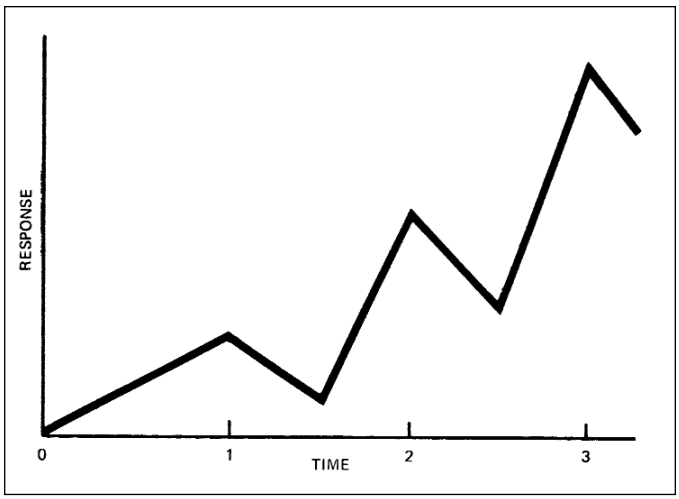


Figure 6–2. Accumulation of a substance in a body is shown in this curve; in this example the level of the substance increases with the duration of exposure.

evidence of injury or impairment can be found; these are called the *No Observable Effect Level* (NOEL).

Lethal Dose

If a number of animals are exposed to a toxic substance, when the concentration reaches a certain level, some but not all of those animals will die. Results of such studies are used to calculate the *lethal dose* (LD) of toxic substances.

If the only variable being studied is the number of deaths, it is possible to use the concept of the LD. The LD_{50} is the calculated dose of a substance that is expected to kill 50 percent of a defined experimental animal population, as determined from the exposure to the substance by any route other than inhalation.

Several designations can be used, such as LD_{50}, LD_0, LD_{100}, and so on. The designation LD_0, which is rarely used, is the concentration that produces no deaths in an experimental group and is the highest concentration tolerated in animals; LD_{100} is the lowest concentration that kills 100 percent of the exposed animals. Although LD_{50} is the concentration that kills half of the exposed animals, it does not mean that the other half are in good health.

Normally, LD_{50} units are the weight of substance per kilogram of animal body weight, usually milligrams per kilogram. The LD_{50} value should be accompanied by an indication of the species of experimental animal used, the route of administration of the compound, the vehicle used to dissolve or suspend the material, if applicable, and the time period during which the animals were dosed and observed.

The slope of the dose-response curve provides useful information. It suggests an index of the margin of safety, or the magnitude of the range of doses between a noneffective dose and a lethal dose. If the dose-response curve is very steep, this margin of safety is slight. One compound could be rated as more toxic than a second compound because of the shape and slope of the dose-response curve (Figure 6–3).

Lethal Concentration

When considering inhalation exposures, the dose by inhalation is needed. *Lethal concentration* (LC) is used for airborne materials. Airborne concentrations may be expressed as *mg/m*^{3} (*milligrams per cubic meter*) or *ppm* (*parts per million*). An LC_{50} means that when a defined experimental animal population is exposed to a calculated concentration of a substance, that concentration (expressed in mg/m^3 or ppm) is expected to kill 50 percent of the animals in a stated length of time.

The duration of exposure is very important because a half-hour exposure might produce an effect that is significantly different in severity or character from that of a 24-hour exposure.

Data accompanying LCs should state the species of animal studied, the length of time the exposure was maintained, and the length of time observation was carried out after exposure.

The dose should be delivered in a specified length of time followed by observation for another specified period of time—this may be hours or days, or even several years when testing for carcinogenesis. For example, in one study animals were exposed for a short time to nitrogen dioxide (NO_2). Initially, there was no observable response, but 36 hours after the exposure, the animals developed a chemical pneumonia and ultimately died. If the animals had been observed for only the first 24 hours after the exposure, the health effects that occurred in the second 24-hour period would have been missed.

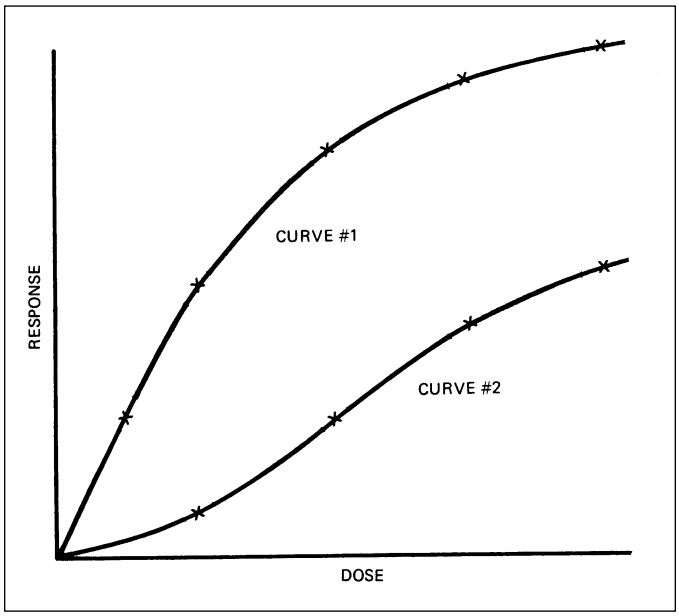


Figure 6–3. The chemical represented by curve #1 has a lower margin of safety and greater toxicity than the curve #2 chemical. In curve #1, the response increases more rapidly as dose increases.

Table 6–A. ***Brief Comparison of Acute, Prolonged, and Chronic Toxicity Tests***

	Acute	*Prolonged*	*Chronic*
Exposure lasts . . .	≤ 24 hours, usually single dose	Typically 2, 4, or 6 weeks	≥ 3 months
Typically yields . . .	Single lethal dose, clinical signs of toxicity	Cumulative dose (if any), major metabolic routes, detoxification or excretion	Potential for carcinogenic effect or other delayed effects
Exemplified by . . .	Potassium cyanide rapidly depriving tissues of oxygen	Carbon tetrachloride causing destruction of liver cells after repeated exposure over several weeks	Carbon tetrachloride causing liver cancer following prolonged exposure (and observation)

Responses

After a substance has been administered, there are criteria the toxicologist uses to evaluate the response.

Examining the organs removed from exposed animals reveals the site of action of the agent, mode of action, and cause of death. Important pathological changes in tissues can be observed following dose levels below those needed to produce the death of animals. The liver and the kidney are particularly sensitive to the action of many agents.

The effect of the agent on the growth rate of the animals is another criterion of adverse response. Relatively low levels of substances that do not produce death or signs of serious illness can result in a diminished rate of growth. The food intake must also be measured to learn whether loss of appetite was a cause of diminished growth.

Changes in the ratio of organ weight to body weight can be used as a criterion of adverse response. In some instances, such alterations are specific to the chemical being tested; for example, an increase of lung weight to body weight ratio can result from pulmonary edema (accumulation of fluid) produced by irritants including ozone and oxides of nitrogen.

Physiological function tests are useful in animal studies and in assessing the response of exposed workers. They can be especially useful in studies of populations with chronic conditions.

Substances can then be rated according to their relative toxicity based on animal data (and human data, if available). Unfortunately, animal experimental data are difficult to interpret and may not apply to human exposure, response, or pathophysiology. Nevertheless, because human dose-response data are not available for most substances, animal data are valuable in estimating the likely range of toxicity of a substance as well as in guiding further investigation.

TIMING: EXPOSURE AND EFFECT

The toxic action of a substance can be arbitrarily divided into acute and chronic effects. In addition to acute and chronic toxicity, we can distinguish acute and chronic exposures (Table 6–A).

Factors other than immediate effects often determine the type and severity of a chemical's adverse effects. For example, acute benzene toxicity (narcosis) has a different clinical picture from that of chronic toxicity (bone marrow depression, leukemia).

Acute Effects and Acute Exposures

Acute exposures and *acute effects* generally involve short-term, high concentrations, and immediate or prompt health effects (illness, irritation, or death). Acute occupational exposures are often related to an accidental exposure.

Acute exposures typically are sudden, of short duration, and are characterized by rapid absorption of the offending material. For example, inhaling high levels of carbon monoxide or swallowing a large quantity of cyanide compound produces illness very rapidly. The health effect of a chemical exposure is considered "acute" when it appears within a short time following exposure, such as within minutes or hours, and the health effect is relatively short-lived.

Chronic Effects and Chronic Exposures

In contrast to acute effects, *chronic effect* or illness is characterized by symptoms or disease of long duration or frequent recurrence. Chronic effects usually develop slowly.

Chronic exposure refers to exposure continued or repeated for a prolonged period, usually years. Standard-setting organizations now try to establish limits that control chronic as well as acute exposures.

Chronic exposure may cause a substance to be continuously present in the tissues. Chronic health effects, illness, or injury can be produced by exposure to a harmful substance that produces irreversible damage so that the injury, rather than the substance, accumulates or progresses. The symptoms of chronic effects are usually different from those seen in acute injury by the same agents. In chronic exposure settings, the level of exposure is often relatively low; the worker is often unaware of the exposures as they occur.

EFFECTS OF EXPOSURE TO AIR CONTAMINANTS

Air contaminants can be classified on the basis of pathophysiological action into irritants, allergens, systemic toxins, or site-specific or organ-specific toxins.

Responses to toxic substances depend on the concentration and duration of exposure. For example, a vapor or gas at one concentration can exert its principal action on the body as an anesthetic, whereas at a lower concentration for a longer exposure time, the same gas or vapor can injure some internal organ or the blood system without causing CNS depression or anesthesia.

Irritation

Irritation is an inflammation or aggravation of the tissue the substance contacts. Contact of some substances with the face and upper respiratory system affects the eyes, the cells lining the nose, and the mouth.

There are many industrial chemicals that at fairly low concentrations irritate tissues with which they come in contact. Irritation results from direct mechanical or chemical (most frequent) reaction with constituents in the tissue having contact. Irritation or inflammation is the major health effect of corrosives.

Many irritants are liquids; for many of these, the degree of local irritation is unrelated to their systemic toxicities. Sometimes differences in viscosity are the determining factors in the type of injury. This applies especially in the lungs, where the inhalation hazard from a substance of low viscosity, such as kerosene, is quite different and more severe than the hazard from a higher viscosity substance such as mineral oil.

To a large extent, the solubility of an irritant gas or vapor influences the part of the respiratory tract that is affected (Table 6–B).

Ammonia, which is very soluble in water, irritates the nose and throat, primarily because the moisture on the surface absorbs and reacts quickly with ammonia. Nitrogen dioxide, which is much less water soluble, acts mainly on the deeper tissues in the lungs as a result of its slower reaction with water/mucous-coated lung structures. Some irritants produce acute pulmonary edema (fluid in lungs), which usually begins as an immediate or intense inflammation that is later manifested by coughing, difficulty breathing, shortness of breath, cyanosis, or coughing up large amounts of mucus. With other chemicals, irritation can be delayed or an immediate reaction can be followed by a period of remission, typically a few hours for phosgene or 24–48 hours for nitrogen oxides. Sensitizing irritants, such as toluene diisocyanate, induce asthmatic bronchitis.

Respiratory irritants can be inhaled in gaseous or vapor form, as a mist, or as particles with a coating of absorbed liquid. Irritants are often grouped according to their site of action (Table 6–B).

Irritants can be subdivided into *primary* and *secondary irritants.* A *primary irritant* is a material that exerts little systemic toxic action, either because the products formed on the tissues of the respiratory tract are nontoxic or because the irritant action at the contact site is far greater than any systemic toxic action.

A *secondary irritant* produces irritant action on mucous membranes, but this effect is overshadowed by systemic effects resulting from absorption. Examples of materials in this category are many of the aromatic hydrocarbons and other organic compounds. The direct contact of liquid hydrocarbons with the lung can cause chemical pneumonitis. Thus, in the case of accidental ingestion of these materials, inducing vomiting is not recommended because some of the vomited hydrocarbon could be breathed (aspirated) into the lungs.

Irritation is generally reversible after short-term exposures. If a worker goes into a cloud of ammonia, immediate irritation is experienced and unless the worker is greatly overexposed, the sensation of pain and irritation will be largely gone very shortly after removal from exposure. However, temporary damage to the respiratory epithelium can make the worker susceptible to other irritants that would otherwise be tolerated. Corrosive substances, such as strong acids and caustics, by contrast, can cause irreversible tissue damage or destruction.

Allergens

Allergens are agents that cause recurrent effects after the worker becomes sensitized (allergic) to the substance. The first few exposures may cause no reaction, but once a person becomes sensitized, reactions can occur from later contact with very small quantities for very short periods of time.

Allergy to a substance almost always presents as eye, skin, or respiratory tract inflammation. Allergic skin effects appear as itching, hives, or eczema (redness, small blisters, cracking). Respiratory skin effects of allergy appear as nasal congestion, sneezing, discharge, or less commonly asthma (bronchospasm) or pneumonia. Eyes can also manifest allergy as itching, redness, or swollen eyelids. Allergy due to industrial exposures does *not* affect the nervous system, liver, kidney, heart, or most other organ systems. Most allergic effects or symptoms begin within minutes or hours following exposure depending on the agent and type of allergy. Symptoms will recur with reexposure.

In other words, allergy causes only eye, skin, or respiratory tract response after exposure to airborne levels often far below PELs, TLVs®, or other occupational guidelines. Once a person develops an allergy to a substance, it will persist for years, if not for life. The occurrence of allergy to one substance does not predict future allergy to another substance although those with allergies to one substance are more likely to develop additional allergies.

Allergy, also known medically as "hypersensitivity," is often confused with hypersusceptibility. *Hypersusceptibility* refers to the occurrence of the usual health effects caused by a substance following exposures to air levels below that associated with effects for most individuals. The substance affects its usual target but at lower doses. If exposure ends, there is no immunologic memory, in contrast to allergy.

Many agents can cause allergic contact dermatitis, including nickel, chromium salts, poison ivy or oak, and epoxy constituents. Known causes of allergic asthma following inhalation exposure include isocyanates, platinum salts, some wood dusts, animal dander, and organic anhydrides. Allergic pneumonia (hypersensitivity pneumonitis) is caused by some molds (farmer's lung) and sugar cane residue (bagassosis).

Table 6–B. ***Comparison of Several Irritants Affecting the Respiratory Tract***

Substance	*Description*	*TLV (2001)**	*Concentrations Exceeding TLV*
		A. Irritants Affecting Upper Respiratory Tract	
Formaldehyde (HCHO)	Aldehyde, colorless gas at ordinary temperatures. Soluble in water up to 55%. (Formalin is aqueous solution).	TLV = 0.3 ppm ceiling based on complaints of irritation <1 ppm, constant prickling irritation, disturbed sleep. Suspected carcinogen.	10–20 ppm causes severe difficulty in breathing, intense lacrimation, severe cough.
Acrolein (CH_2=CHCHO)	Aldehyde, colorless or yellowish liquid. Water soluble.	TLV = 0.1 ppm ceiling low enough to minimize, but not entirely prevent, irritation in exposed individuals.	1 ppm may be strongly irritating to eyes and nose within five minutes or less. 8–10 ppm lethal within four hours or less; 100 ppm and above may be lethal within a short time.
Ammonia (NH_3)	Alkali, colorless gas. Soluble in water; pungent odor detected as low as 1 ppm.	TLV = 25 ppm should protect against irritation to eyes and respiratory tract, minimize complaints of discomfort among unacclimated individuals.	Irritation of respiratory tract and conjunctiva in workers inhaling 100 ppm. Severe eye damage, lung and airway dysfunction at higher concentrations.
Sulfur dioxide (SO_2)	A colorless nonflammable gas with acid odor, pungent taste, one of the most common community air pollutants.	TLV SO_2 = 2 ppm expected to prevent irritation and accelerated loss of pulmonary function in most workers.	High acute exposure causes intense irritation, death may follow from suffocation due to respiratory paralysis or pulmonary edema. Industrial poisoning usually chronic—may develop as pulmonary dysfunction progressing to emphysema.
		B. Irritants Affecting Both Upper Respiratory Tract and Lung Tissues	
Chlorine (Cl_2)	Halogen, greenish-yellow gas with suffocating odor, which may be noticeable at 1–4 ppm. Soluble in water up to 0.8% by weight.	TLV = 0.5 ppm to minimize chronic lung changes, accelerated aging, teeth erosion.	30 ppm produces intense coughing.
Ozone (O_3)	Bluish or colorless explosive gas or blue liquid. Pleasant characteristic odor in concentrations of less than 2 ppm. Slightly water-soluble, used as disinfectant.	TLV = 0.05 ppm (heavy work), which causes no symptoms but may result in slightly reduced lung function.	Daily intermittent exposure above 5 ppm may cause incapacitating pulmonary congestion. Lung function changes are dose-dependent and reversible at lower doses.
		C. Irritants Affecting Primarily Terminal Respiratory Passages and Air Sacs	
Nitrogen dioxide (NO_2)	Reddish-brown gas with irritating odor. Decomposes in water, nitric acid (HNO_3), and nitric oxide (NO).	TLV = 3 ppm, considered sufficiently low to ensure against reduced respiratory function.	10–20 ppm may cause mucosal irritation or chronic disease. 100–500 ppm may lead to sudden death, insidious, delayed, and potentially lethal pulmonary edema (most characteristic), delayed inflammatory changes leading to death several weeks after exposure.
Phosgene (carbonyl chloride) ($COCl_2$)	Colorless, nonflammable gas. Suffocating odor when concentrated, otherwise odor suggestive of decaying fruit or moldy hay. Slightly soluble in water and hydrolyzed by it.	TLV = 0.1 ppm because of its irritating effects on the respiratory tract at levels slightly above 0.1 ppm.	3 ppm causes immediate throat irritation, 50 ppm rapidly lethal.

TLVs are from the ACGIH 2001 TLVs® and BEIs®.

SYSTEMIC TOXINS

Asphyxiants are systemic toxins that interfere with oxygenation of the tissues and the affected individual may suffocate. This class is divided into *simple asphyxiants* and *chemical asphyxiants*.

Simple Asphyxiants

Simple asphyxiants are most often inert gases that dilute or displace atmospheric oxygen from the breathing zone or air supply. Blood levels become insufficient for normal tissue respiration. Common examples are carbon dioxide, ethane, helium, hydrogen, methane, and nitrogen. However, any substance in gaseous form can replace oxygen in the breathing zone and in excessive quantity cause asphyxiation.

Asphyxiants deprive the body of the needed oxygen that must be transported from the lungs via the bloodstream to all cells. With complete deprivation of oxygen, brain cells die in 3–5 min. Total asphyxiation leads to complete absence of oxygen in the blood (anoxia). Partial asphyxiation leads to low levels of oxygen in the blood (hypoxia). If allowed to continue too long, hypoxia also can result in brain damage or death.

Chemical Asphyxiants

Through their direct chemical action, chemical asphyxiants prevent the uptake of oxygen by the blood, interfere with the transportation of oxygen from the lungs to the tissues, or prevent normal oxygenation of tissues even when the blood is well oxygenated. Carbon monoxide prevents oxygen transport by preferentially combining with hemoglobin. Hydrogen cyanide inhibits enzyme systems, particularly the cytochrome oxidase system necessary for cellular oxygen use. Hydrogen sulfide paralyzes the respiratory center of the brain and the olfactory nerve. At sufficiently high levels, all three of these chemical asphyxiants can cause almost instantaneous collapse and unconsciousness (Table 6–C).

The principal action of carbon monoxide is its interference with the delivery of oxygen to the tissues. The concentration of carbon monoxide required to cause death is small compared with the lethal amount for simple asphyxiants. Carbon monoxide occupies oxygen's usual binding site on hemoglobin, thus preventing the transport of oxygen through the bloodstream to all cells. Hemoglobin combines with carbon monoxide much more readily than it does with oxygen by a ratio of approximately 300 to 1.

Another example of a chemical asphyxiant is hydrogen cyanide. It is transported by the bloodstream to the individual cells of the body, where it blocks oxygen uptake at the cellular level by combining with the enzymes that control cellular oxidation.

Organ-Specific Effects

Most substances do not damage all organs or systems, but affect a few or one specific organ. For example, most organic hydrocarbons cause central nervous system (brain) depression; corrosive acids and alkalis injure skin, mucous membranes, eyes, and lungs. Some agents cause unique effects, such as cancer (e.g., benzene), reproductive effects (e.g., lead) or even liver damage (e.g., carbon tetrachloride) This section highlights a selection of organ-specific effects and their causative substances.

CENTRAL NERVOUS SYSTEM DEPRESSANTS

Central nervous system depressants (CNSDs) exert their principal action by causing simple anesthesia without serious systemic effects, unless the dose is massive. Depending on the concentration, the depth of anesthesia ranges from mild symptoms (e.g., headache, dizziness, lack of coordination, confusion) to complete loss of consciousness and death.

CNSDs include aliphatic alcohols (such as ethyl and propyl), aliphatic ketones (such as acetone and methyl-ethyl-ketone), aromatic hydrocarbons, ethers (such as ethyl and isopropyl), and short-chain halogenated hydrocarbons.

CARDIAC SENSITIZATION

Inhalation of certain volatile hydrocarbons can make the heart abnormally susceptible to epinephrine (adrenalin). The epinephrine then causes abnormal, dangerous cardiac rhythms, usually ventricular in origin. This has been observed with solvent misuse such as sniffing aerosols or glue, and exposure to some industrial solvents (chlorocarbons) and chlorofluorocarbon (CFC) refrigerants at levels grossly exceeding the recommended TLV.

NEUROTOXIC EFFECTS

Neurotoxic agents damage the nervous system. Metals such as manganese, lead, and mercury are examples. The central nervous system seems particularly sensitive to organometallic compounds.

A different neurotoxic effect involves acetylcholine, a neurotransmitter. In the transfer of electrical impulses (nerve conduction) from one part of the nerve to the next part, the chemical acetylcholine is essential, and the enzyme cholinesterase maintains acetylcholine at the proper levels. When acetylcholinesterase is inhibited, the acetylcholine increases and may reach a level incompatible with the orderly transfer of electrical impulses.

Nerve conduction abnormalities occur that result in nervous system failure. Some cholinesterase inhibitors include organic phosphate and organophosphate pesticides such as parathion or carbamate pesticides such as carbofuran.

Other neurotoxic effects include neurasthenia and peripheral neuropathy. Neurasthenia involves emotional irritability and loss of intellectual function; it is associated with prolonged (years) exposure to some hydrocarbon solvents (such as styrene and toluene). Peripheral neuropathy involves loss of limb strength or sensation; it is associated with exposure to agents such as lead, hexane, and acrylamide.

PULMONARY EFFECTS

In considering health effects from inhaled dust, primary concern is given to solid material that is small enough to enter

Table 6–C. ***Comparison of Some Chemical Asphyxiants***

Substance	*Description*	*TLV 2001*	*Concentrations Exceeding TLV*
Hydrogen cyanide (HCN)	Colorless liquid or gas, flammable, inhibits cellular respiration, almond-like odor.	TLV = 4.7 ppm (5 mg/m^3) ceiling, which may give a seven or eightfold margin against lethal effects.	18–36 ppm causes slight symptoms after several hours, 90 ppm fatal after 30 to 60 minutes, 270 ppm immediately fatal.
Carbon monoxide (CO)	Colorless, odorless gas, sparingly soluble in water, that combines with hemoglobin to form carboxyhemoglobin (COHb), which interferes with oxygen transport to tissues and removal of CO_2 from tissues.	TLV = 25 ppm (29 mg/m^3), based on an air concentration that should not generally result in COHb levels above 10%. Heavy labor, high temperatures, or altitudes 5,000– 8,000 feet above sea level may require 25 ppm TLV.	Fatal in 1 minute at 1% concentration (= 10,000 ppm), which causes approximately 20% COHb. Severe poisoning from short exposure often followed by complete recovery but neurological, cardiovascular, pulmonary, other complications may occur.
Hydrogen sulfide (H_2S)	Colorless flammable gas, burns to sulfur dioxide. Soluble in water but solutions unstable heavier than air. Characteristic odor of rotten eggs detectable at concentrations of 0.02 ppm or appreciably less. Higher toxic concentrations can rapidly deaden sense of smell. Inhibits cellular respiration.	TLV = 5 ppm (14 mg/m^3), based primarily on eye effects and CNS depression.	Concentrations of 300–1000 ppm cause rapid unconsciousness and death through respiratory paralysis. Associated with an unusual diversity of symptoms including chronic keratoconjunctivitis, nausea, insomnia, pulmonary edema, balance disorders, polyneuritis, and gray-green discoloration of the teeth.

the alveoli. A certain amount of filtration by the upper respiratory system prevents large particles from getting into the lung. In the workplace, particles are dispersed in a nonuniform way and in a full spectrum of sizes; only a portion of them are small enough to get into the lung.

Inert dusts previously termed nuisance dusts are now called *Particulates* (insoluble) *Not Otherwise Classified* (PNOC). The definition of inert is relative because all particulates evoke a tissue response when inhaled in sufficient amount. The TLV for PNOC has been set at 10 mg/m^3 (inhalable fraction) or 3 mg/m^3 (respirable fraction). This is provided that the particulate matter contains no asbestos and less than one percent crystalline silica.

Chronic exposure to some dusts (asbestos, silica, coal) is associated with various types of pneumoconiosis (lung disease caused by dust). (See Chapter 8, Particulates.)

Pneumoconioses associated with inert dusts are sometimes called benign pneumoconioses.

Fibrotic (formation of scar tissue) changes are produced by materials such as crystalline silica, which produces a silicotic nodule or small area of scarlike tissue. Asbestos also produces typical fibrotic damage to lung tissue (asbestosis) as well as various cancers. There is concern about the possible effects of nonoccupational exposure to asbestos.

Asbestos and smoking illustrate the concept of synergy, in which the combined risk from two separate causes of a health effect (lung cancer) far exceeds the sum of their individual risks.

In combination with smoking, exposure to airborne asbestos fibers leads to an excessive incidence of lung cancer. The incidence of lung cancer to nonsmokers exposed to asbestos, though lower, is still abnormally high. Asbestos exposure has also been shown to cause mesothelioma, which in nonasbestos-exposed people is a very rare cancer of the lining of the abdomen or the lung. (See Chapter 8, Particulates, for more information on asbestos-related diseases and other pneumoconioses.)

Some inhaled particles gain entrance to the body through the lung. Although they may not damage the lung tissues, they are absorbed into the blood and distributed throughout the body and can damage the nervous system, kidney, liver, or other organs.

The effects that result from heavy metals being absorbed through the respiratory tract vary appreciably from substance to substance. Often there is slow, cumulative absorption and retention of metal in the body; however, health effects may develop so slowly that the source or cause of the symptoms is often not initially recognized (e.g., lead, mercury).

Inorganic lead is a good example of a substance with unique effects in multiple organs. Excessive exposure to the inorganic form usually results from ingestion or inhalation of dust or fume, causing physical abnormalities that are characterized by anemia, headache, anorexia, weakness, and weight loss. With chronic, high exposures, more serious reactions include bone marrow changes and peripheral neuropathy, kidney injury, reproductive effects, and brain injury.

Organic lead, unlike inorganic lead, tends to concentrate in the brain. Some organic lead materials can easily be absorbed through the skin and add to the hazard from ingestion or inhalation. A single exposure to tetraethyl lead can

cause symptoms in a few hours and absorption of a relatively small amount can be fatal.

Although mercury poisoning was described by Paracelsus among miners several centuries ago, it has received much more attention recently. Inorganic compounds of mercury are readily absorbed from the intestine and tend to concentrate primarily in the kidneys, but can also damage the brain. Organic mercury tends to be especially concentrated in blood and the brain.

Industrial manganese poisoning, except for its action related to metal fume fever, is primarily a chronic disease resulting from inhalation of fume or dust in the mining or refining of manganese ores. It also can be caused by cutting and welding metals containing high manganese content while in a confined space without respiratory protection. Manganese poisoning is noted for its peculiar neurological effects, especially psychomotor instability.

Carcinogenesis

Although any new and abnormal tissue growth can be classed as a neoplasm, this term is most often used to describe cancerous or potentially cancerous tissue. The cells of a cancer are out of control. If neoplastic cells invade tissues or spread to new locations in the body (metastasize) the neoplasm has become cancerous or malignant. Cancer cells infrequently perform a useful function or one similar to that of the cells they destroy and replace.

It is well established that exposure to some chemicals can produce cancer in laboratory animals and humans. In common usage, *carcinogen* refers to any agent that can produce or accelerate the development of malignant or potentially malignant tumors or malignant neoplastic proliferation of cells. Carcinogen refers specifically to agents that cause carcinoma, but the current trend is to broaden its usage to indicate an agent that possesses carcinogenic potential. The terms tumorigen and oncogen are used synonymously with carcinogen.

A number of factors have been related to the incidence of cancer—the genetic makeup of the host, viruses, ultraviolet and ionizing radiation, hormone imbalance, and exposure to certain substances. Other factors such as cocarcinogens and tumor accelerators can be involved. For some substances a combination of factors must be present to induce cancers.

DEFINITIONS

Carcinogenesis has several possible definitions. A *carcinogen* can be defined as a substance that will induce a malignant tumor in humans following a reasonable exposure. A carcinogen has also been defined as a substance that will induce any neoplastic growth in any tissue of any animal at any dose by any method of application applied for as long as the lifetime of the animal.

Problems arise when all substances that would fulfill the second definition in the experimental laboratory are classified as carcinogens and it is assumed that they will cause malignancies in humans in accordance with the first definition. According to NIOSH, a substance is considered a suspected carcinogen to humans if it produces cancers in two or more animal species.

Even if we could extrapolate from a specific strain of a laboratory animal to all species including humans, taking into consideration such factors as weight, surface area, metabolic profiles, and drug-induced changes in metabolism, carcinogenic potential is often difficult to estimate because of interactions with other agents or biological susceptibilities.

Chemicals that induce cancer do so by mechanisms that are not completely defined. It is generally believed that the transformation of a cell from a normal to a carcinogenic state is multistaged and influenced by both internal and external factors. For example, some materials can produce cancer in the lungs after inhalation whereas others pass through the lung as a route of entry and produce the cancer elsewhere.

A toxicologist can look at the structure of an organic chemical and speculate that because of certain functional groups the chemical is carcinogenic but another chemical having similar functional groups is not carcinogenic. The theories that explain why a chemical is carcinogenic are very involved and, as yet, imperfect.

TYPICAL CARCINOGENS

Coal tar and various petroleum products have been identified as skin and subcutaneous carcinogens. Pitch, creosote oil, anthracene oil, soot, lamp black, lignite, asphalt, bitumen, certain cutting oils, waxes, and paraffin oils have also been implicated as potential carcinogens.

Workers can be exposed to arsenic, also recognized as a carcinogen, in the manufacture or use of roasting metallic sulfide ores as well as certain paints or enamels, dyes or tints, pesticides, and miscellaneous chemicals.

Inorganic salts of metals such as chromium, beryllium, and to a lesser extent nickel compounds are associated with cancer of the respiratory tract, usually the lungs. Other metals such as lead and cobalt are suspect, but their direct toxic effects in humans can obscure carcinogenic potential.

Leukemia is a group of diseases characterized by widespread, uncontrolled proliferation and abnormal accumulation of white blood cells and the failure of many of these cells to reach maturity. Exposures to ionizing radiation and benzene are principal occupational causes. Benzene exposure is also associated with blood dyscrasias (diseased state of the blood, generally involving abnormal or deficiently formed cellular elements), which may progress to leukemia or aplastic anemia.

Osteogenic sarcomas (bone tumors) have been detected in workers who applied radioactive luminous paint to instrument and watch dials. Angiosarcomas (a relatively rare malignant growth) of the liver have been found to be associated with human exposure to vinyl chloride monomer. Oat-cell carcinomas of the lung have been found in workers exposed to bis (chloromethyl) ether (BCME). BCME exposure can

occur as an unsought intermediate in certain reactions involving formaldehyde and hydrochloric acid. BCME is carcinogenic by inhalation, skin, and subcutaneous routes in animals.

The result of exposure to chemical carcinogens is such that people who absorb a chemical carcinogen such as benzidine are at increased risk of getting bladder cancer. With many carcinogens (Table 6–D), it is clear that there is a higher incidence of cancer in certain groups of people who are exposed to carcinogenic materials. For a more complete listing and discussion of carcinogens, consult the websites of IARC and the National Toxicology Program.

ENVIRONMENTAL FACTORS

Cancer is considered so insidious and has such severe health effects that carcinogenic substances are isolated and looked at more carefully than all others. The statement that 80–90 percent of all cancers are environmentally caused does not mean that 80–90 percent of cancers are caused by industry. The environment includes not only the air we breathe and water we drink but our diet and all elements of our lifestyle, on and off the job. The predominant causes of environmental cancer are tobacco smoke and diet.

Mutagenesis

A *mutagen* is an agent that affects the genetic material of the exposed organism. It may cause cancer, birth defects, or undesirable effects in later generations. People who work with a certain chemical may not be harmed, but their offspring can be.

The problem of time lag between exposure and effect is particularly severe for mutagenic agents. Mutations will not show up until the next generation at the earliest, and may not appear for several generations. The long latency makes it difficult to discover the connection between the exposure and manifestation of genetic damage.

Mutagens are chemical or physical agents that cause inheritable changes in the chromosomes. A mutagen might have an effect on somatic cells but not on germ (reproductive) cells. In this case, its effects are not passed on to offspring, but depend on the kind of cell affected. For example, the (somatic) cells of the bone marrow go on multiplying through life and shed the products of division into the blood, where they function for a time as red and white blood cells before they are removed and replaced. Gross interference with the genetic material of such cells may make cell division ineffective.

A mutagenic effect on somatic cells can also make them capable of more rapid growth and multiplication, so that they are formed far more rapidly than they can be removed from the blood, where they interfere with normal body functions. If the white cells are affected in this way, the outcome is a leukemia.

Similar interference with the genetic material could theoretically start up division in cells that do not normally divide during adult life. If the products of such division displace or invade normal tissues, the result is a solid tumor or cancer. In both these instances, the mutagen responsible would have manifested activity as a carcinogen.

Reproductive Toxicity

Reproduction results from a complex series of events involving both parents. It begins with each parent's genetic contribution (chromosome) and ends with expression of the genes acquired by the offspring. Every step in the reproductive process is vulnerable to effects from external physical and chemical agents. Chromosomal replication, sexual function, ovulation, conception/fertilization, embryo implantation, placental function, fetal development, labor, delivery, and even child development are components of the reproductive process. Table 6–E lists known or suspected human reproductive toxins. Reproductive abnormalities include changes in sperm count, sperm motility, libido, menstruation and cycle length, and fertility rate; these and other changes can result in miscarriage, embryo toxicity, developmental defects, and stillbirth (Tables 6–F, 6–G).

Teratogenesis (congenital malformation) results from interference with normal embryonic development by a biological, chemical, or physical agent. Exposure of a pregnant female may, under certain conditions, produce malformations of the fetus without inducing damage to the mother or killing the fetus. Such malformations are not hereditary. In contrast, congenital malformations resulting from changes in the genetic material are mutations and are hereditary.

TYPICAL TERATOGENS

Agents currently identified as human teratogens include infections such as rubella, metals such as lead and mercury, chemicals including PCBs, and ionizing radiation.

PREGNANT WOMEN IN THE WORKPLACE

A teratogen, by definition, is different from a mutagen in that it must affect a developing fetus. This is extremely important today because of the very considerable pressure to address the topic of pregnant women in the workplace.

The fetus is protected from some toxic chemicals because the placenta prevents them from entering the fetal bloodstream; however, many toxic chemicals, such as lead, easily cross the placenta. Damage to the fetus (embryo) is most likely to occur in early pregnancy, particularly during the first 8–10 weeks. During much of this critical period, many women are not even aware that they are pregnant.

It can be extremely difficult to establish specific cause-and-effect relationships between a teratogen and the birth defect it can produce. Animal studies must be supplemented with epidemiologic data and it may be decades before researchers know with certainty what substances hold how much risk for which unborn infants.

The fact that there are pregnant women in the workplace

Table 6–D. ***Carcinogens with Possible Occupational Relevance****

Substances Known to Be Carcinogenic		
4-aminobiphenyl	Bis (chloromethyl) ether and technical-grade chloromethyl methyl ether	Erionite
Arsenic and certain arsenic compounds	1-(2-chloroethyl)-3-(4-methylcyclohexyl)-1-nitrosourea (MeCCNU)	2-naphthylamine
Asbestos	Chromium and certain chromium compounds	Thorium dioxide
Benzene		Vinyl chloride (monomer)
Benzidine		
Radon		
Substances That May Reasonably Be Assumed to Be Carcinogenic		
Acetaldehyde	Diglycidyl resorcinol ether	Polychlorinated biphenyls
2-acetylaminofluorene	3,3'-dimethoxybenzidine and 3,3'-dimethoxybenzidine	Polycyclic aromatic hydrocarbons (such as benz(a)anthracene and benzo(a)pyrene)
Acrylamide	3,3'-dimethylbenzidine	Nitrilotriacetic acid
Acrylonitrile	Dimethylcarbamoyl chloride	B-propiolactone
2-aminoanthraquinone	4-dimethylaminoazobenzene	Propylene oxide
O-aminoazotoluene	Dimethyl sulfate	Polybrominated biphenyls
1-amino-2-methylanthraquinone	Dimethylvinyl chloride	Silica, crystalline (respirable) in the form of quartz, cristobalite, and tridymite
Amitrole	1,1-dimethylhydrazine	Sulfallate
O-anisidine hydrochloride	Epichlorohydrin	1,3-propane sultone
Benzotrichloride	Ethyl acrylate	Tetrachloroethylene (perchloroethylene)
Beryllium and certain beryllium compounds	1,4-dioxane	Thiourea
Bromodichloromethane	Ethyl methanesulfonate	Selenium sulfide
1,3-butadiene	Formaldehyde (gas)	O-toluidine and o-toluidine hydrochloride
Butylated hydroxyanisole	Ethylene oxide	Toxaphene
Cadmium and certain cadmium compounds	Hexamethylphosphoramide	2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)
Carbon tetrachloride	Hydrazine and hydrazine sulfate	Toluene diisocyanate
Chlorendic acid	Ethylene thiourea	2,4,6-trichlorophenol
Chlorinated paraffins (C_{12}, 60% chlorine)	Kepone (chlordecone)	Ceramic fibers
Chloroform	Lead acetate and lead phosphate	Chlordecone
3-chloro-2-methylpropene	Hexachlorbenzene	Chloro-o-toluidine
4-chloro-o-phenylenediamine	2-methylaziridine (propyleneimine)	Chloro-o-toluidine hydrochloride
P-cresidine	4,4'-methylene bis (2-chloroaniline) (MBOCA)	Dinitropyrene
DDT	Hydrazobenzene	Danthron
2,4-diaminotoluene	4,4'-methylendianiline and its dihydrochloride	Glasswool
1,2-dibromo-3-chloropropane	Methyl methanesulfonate	Glycidol
1,2-dibromoethane (EDB)	Lindane and other hexachlorocyclohexane isomers	Furan
1,4-dichlorobenzene	Michler's ketone	Hexachloroethane
1,4-dichlorobenzidine and 3,3'-dichlorobenzidine dihydrochloride	Nickel and certain nickel compounds	Nitroanisole
1,2-dichloroethane	4,4'-methylene bis (N,N-dimethyl) benzenamine	Nitrochrysene
Dichloromethane (methylene chloride)	2-nitropropane	Nitropyrene
1,3-dichloropropene (technical grade)	4,4'-oxydianiline	Tetranitromethane
Diepoxybutane	N-methyl-n'-nitro-n-nitrosoguanidine	Trichloropropane
Di(2-ethylhexyl)phthalate		Vinyl cyclohexene diepoxide
Diethyl sulfate		
Occupational Exposures Associated with a Technological Process That Are Known to Be Carcinogenic		
Coke oven emissions	Mineral oils	
Soots	Tars	

* Known carcinogens are substances for which evidence from human studies indicates that there is a causal relationship between exposure to the substance and human cancer. Substances that may reasonably be expected to be carcinogens are those for which there is limited evidence of carcinogenicity in humans or sufficient evidence of carcinogenicity in experimental animals. (Adapted from Eighth Annual Report on Carcinogens, 1998 National Toxicology Program.)

and that they can be exposed to teratogens leads to a problem in setting occupational health standards. An embryo of a few weeks or a fetus of a few months should be given consideration and should not be exposed to a toxic environment. Although one way to solve this problem is to restrict the activities of fertile women in the workplace, this practice is no longer legally acceptable (*Auto Workers vs. Johnson Controls*). Also, the potential for adverse effects on the male reproductive system cannot be overlooked. *The workplace should be such that fertile men and women are able to work there without likelihood of harm.*

BASIS FOR WORKPLACE STANDARDS

Chemical analogy, in-vitro testing, animal experimentation, and human epidemiologic data are the bases for establishing

Table 6–E. ***Selected Occupational Agents Known or Strongly Suspected to Cause Human Reproductive Toxicity***

Developmental Effects	*Female Reproductive Toxicity*
Carbon disulfide	Alkylating/antineoplastic agents
Carbon monoxide	Arsenic
Ethylene glycol monoethyl ether	Carbon disulfide
Ethylene glycol monoethyl ether acetate	Ethylene oxide
Ethylene glycol monomethyl ether	Ionizing radiation
Ethylene glycol monomethyl ether acetate	Lead
Ionizing radiation	Mercury
Lead	Solvent exposure
Mercury (compounds)	*Male Reproductive Toxicity*
Methyl bromide	Carbon disulfide
Polychlorinated biphenyl (PCB)	Cyclohexanone
Ribavirin	1,2-dibromo-3-chloropropane (DBCP)
2,3,7,8-tetrachlorodibenzo para dioxin (TCDD)	Dinitrobenzene
Arsenic	Ethylene glycol ethers
Cadmium	Ethylene dibromide
Chlordecone	Chlordecone
	Estrogens
	Heat
	Ionizing radiation
	Epichlorohydrin
	Lead

workplace standards for substances. They are described in the following sections.

Chemical Analogy

When dealing with a new chemical, animal or human toxicity data are usually unavailable. Therefore, the nature of response to a chemical can be assumed to be analogous to that produced by contact with a substance with a similar chemical and biological structure. Chemicals that are similar have been assumed initially to produce similar biological responses. Computerized modeling uses structure-activity data, chemical analogy, and other data to derive estimates of toxicity and toxicokinetics.

In-Vitro Testing

In-vitro means "in a test tube." As a result of increasing costs and social pressures to eliminate use of animals for toxicological testing, laboratory methods are being developed to study toxicity and health effects. Depending on the effect or property being studied, different test materials or biological media may be used. For example, bacteria (*Salmonella*) are grown on a plate and exposed to a chemical to determine its mutagenicity (Ames test). Similarly target organ cells (e.g., skin, liver) can be grown in culture and exposed to a chemical to determine the reaction at the molecular or cellular level. Other tests being developed or in use involve human or animal tissue and cells, microbial agents (protozoa, helminths), artificial human organs or tissue and even DNA.

Animal Experimentation

Before introducing chemical agents into the workplace, it is advisable to know their toxic effects. Then preventive measures can be designed to protect workers and emergency procedures can be put in place to minimize accidental exposure. Because there is often little or no information available about new chemicals, an important method of developing such new information quickly is animal experimentation.

EXPOSURE STANDARDS

The toxicological effects of vapors, gases, fumes, and dusts are initially determined in the laboratory can be estimated by actually exposing animals to known concentrations for controlled periods of time.

Groups of animals can be exposed to controlled concentrations for eight hours a day, five days a week, for weeks, months, or years. Animals must be observed daily to ascertain any untoward physiological responses during exposure and post-exposure periods. On terminating chronic experiments, all animals are sacrificed and the internal organs are weighed and examined histopathologically. In this manner, the toxicologist gains information regarding no-effect levels as well as levels that produce injury.

SCREENING PROCEDURES

Toxicological screening should ideally include both acute toxicity studies, studies of repeated administration at short intervals, and long-term studies performed during the lifespan of the animal, and in some instances over several generations.

Because biological variations influence the reaction to a foreign substance in different species, it is difficult to duplicate in animal experiments the precise situation to which humans can be exposed. In the development of a specific test program, preliminary studies are necessary to select species that absorb and metabolize related classes of chemicals in ways similar to humans.

A route of administration different from that usually occurring in humans, such as parenteral (injected, i.e., intravenous, intramuscular, etc.) administration instead of inhalation or ingestion, can give misleading results.

Chronic toxicity studies involve repeated administration of test substances. However, chronic effects can also be expected from a single exposure to a substance if the body stores the material so that it remains in the organism for long periods of time or if the health effect is delayed or permanent. Repeated administration of the test substance is useful in the investigation of such problems as cumulative toxicity, tolerance, and enzyme-induction phenomena.

PROBLEM AREAS

Animal testing provides only an estimate of the toxicity of a chemical for humans. It is very difficult to extrapolate an LD_{50} or an LC_{50} to an acceptable Threshold Limit Value.

Because the primary concern is the prevention of harm to humans, the limitations inherent in animal-derived data

Table 6–F. ***Measures of Human Reproductive Function Readily Obtainable Before Fertilization***

	Affected Individual		
Endpoint	*Male*	*Both*	*Female*
Sexual function	Erection Ejaculation	Libido Behavior	
Endocrine system		Luteinizing hormone Follicle-stimulating hormone Steroid hormones (androgens, estrogens, and progestins)	Cervical mucus quality
Germ cells	Sperm number Sperm motility Sperm shape Chromosomal integrity Fertilizing ability		
Fecundity (ability to conceive)	Testicular integrity Semen quality	Integrity of external genitalia	Ovarian integrity Blockage of oviduct Menstrual regularity Amenorrhea Anovulatory cycles
Secondary sexual characteristics		Breast development Facial and axillary hair growth Sebaceous glands	
Reproductive lifespan		Age at puberty	Age at menopause

(From U.S. Congress, Office of Technology Assessment. *Reproductive Health Hazards in the Workplace,* Chapter 3, Table 3–1. Washington, DC: U.S. Government Printing Office, OTA-BA-266, Dec. 1985.)

Table 6–G. ***Measures of Human Reproductive Function Readily Available After Fertilization***

	Affected Individual		
Endpoint	*Female*	*Both*	*Offspring*
Endocrine system	Human chorionic gonadotropin Steroid hormones, especially progesterone		
Health during pregnancy	Hemorrhage Toxemia	Fetal death Spontaneous abortion	Morphology Chromosomal aberrations
Perinatal period		Premature birth Postmature birth	Death Chromosomal aberrations Birth defects Birth weight Apgar score
Postnatal period	Lactation		Infant death Childhood morbidity Childhood malignancies Development Behavior
Reproductive lifespan	Age at menopause		

(From U.S. Congress, Office of Technology Assessment. *Reproductive Health Hazards in the Workplace,* Chapter 3, Table 3–2. Washington, DC: U.S. Government Printing Office, OTA-BA-266, Dec. 1985.)

should be recognized. Whether human response will resemble that of the most reactive or the least reactive species tested is often not known. Finally, whether the animal response is an exact parallel to human response cannot always be predicted.

Human Epidemiological Data

Records of human experience for exposures to many substances are available. This is particularly true for older chemicals such as carbon monoxide and lead. Epidemiological data can be descriptive, retrospective, or prospective; it pertains to health effects that are measured in groups of exposed humans.

Descriptive studies identify a change or difference in prevalence of a disease in a subgroup of the population.

Retrospective studies reveal a relationship between a substance and a certain effect caused by exposure that occurred months or years before the initiation of data collection.

Prospective studies can define more precisely the time relationship and the magnitude of risk. Prospective studies are

present and future continuing studies that measure health effects as the exposures occur in work areas.

Epidemiological analysis may reveal the relationship between time of occurrence of an adverse effect and age at the time of the first exposure. Epidemiological study and analysis attempts to identify or clarify the influence of variables other than the agent under study. For example, cigarette smoking in the study of lung cancer among asbestos workers is such a variable.

Finally, if a specific chemical is removed from the environment, it should be followed by epidemiological evidence of a decline in the frequency of the effect.

FEDERAL REGULATIONS

The federal regulations with implications for industrial toxicology include the Federal Occupational Safety and Health Act of 1970, the Toxic Substances Control Act of 1976, and various NIOSH, OSHA, and voluntary professional standards. These are covered in the following sections.

Occupational Safety and Health Act (OSHAct)

The Occupational Safety and Health Act (*OSHAct, enacted in 1970*) is administered by the Occupational Safety and Health Administration (OSHA), which has the regulatory authority to protect workers from physical hazards and hazardous substances and forms of energy (such as noise and radiation) in the work environment. OSHA monitors health and safety in the workplace, setting standards for worker exposure to specific chemicals, for permissible exposure levels (PELs), and for monitoring procedures. It also provides research, information, education, and training in occupational safety and health. By establishing the National Institute for Occupational Safety and Health (NIOSH), the act provided for studies to be conducted so that regulatory decisions can be based on the best available information.

In 1983, OSHA enacted the Hazard Communication Standard, 29 *CFR* 1910.1200, which sets standards for worker notification and training for chemicals in the workplace. This also is known as the "Hazcom" or "right-to-know" Regulation. For more information on hazard communication, see Chapter 28, Government Regulations, and Chapter 29, History of the Federal Occupational Safety and Health Administration.

OSHA has adopted exposure limits (PELs) for more than 400 substances. Many are based on Threshold Limit Values (TLVs®) suggested for industrial chemical exposures by the American Conference of Governmental Industrial Hygienists (ACGIH).

The ACGIH TLVs® were directed primarily at substances that caused physiological reactions such as poisoning, irritation of eyes and respiratory tract, and skin rashes. The original TLVs were not established on the basis of carcinogenic, teratogenic, or mutagenic properties, and synergistic effects of chemical mixtures were not included in tests used to determine the TLVs. Since OSHA began (1971), new standards for carcinogenic and other chemical agents have been promulgated by OSHA. ACGIH has also been updating and adding to its original list of TLVs. See Appendix B for a complete listing of the ACGIH TLVs®.

The American National Standards Institute (ANSI), through its former Committee on Acceptable Concentrations of Toxic Dusts and Gases, also published standards on levels of materials in the air in work areas. OSHA has adopted some ANSI standards because ANSI was considered to be a consensus standard-setting group.

TSCA

The Toxic Substances Control Act of 1976 (*TSCA*) is administered by the Environmental Protection Agency (EPA) and covers almost all chemicals manufactured in the United States, excluding certain compounds covered under other regulations such as the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). The act requires that chemical manufacturers and processors develop adequate data on the health and environmental effects of the chemicals they produce. The EPA is required to establish standards for the testing of chemicals.

Companies are required to notify the EPA 90 days before manufacturing any new chemical and to provide test data and other information about the safety of the product. The EPA has the authority to ban or regulate such chemicals if test information is insufficient and if the chemical is to be produced in substantial quantities with wide distribution. The EPA is required to ban or restrict the use of any chemical presenting an unreasonable risk of injury to health or the environment.

Toxic Substances List

The Occupational Safety and Health Act requires the annual publication of a list of all known toxic substances by generic, family, or other useful grouping, and the concentrations at which such toxicity is known to occur. OSHA also requires employers to monitor employee exposure to toxic materials and to keep records of such exposure.

The Registry of Toxic Effects of Chemical Substances (RTECS) is a compendium of toxicity data extracted from the scientific literature by the U.S. Department of Health and Human Services. It is intended to serve as the required toxic substances list.

The purpose of the Toxic Substances List is to identify all known toxic substances in accordance with standardized definitions that can be used to describe toxicity. The entry of a substance on the list does not automatically mean that it is to be avoided but that the listed substance has been found to be hazardous at the doses or exposure levels listed.

The absence of a substance from the list does not necessarily indicate that a substance is not toxic but rather that the dose that causes the toxic effect is not known.

There has been no attempt at an evaluation of the degree of hazard that might be expected from substances on the list; that is a goal of the hazard-evaluation studies.

HAZARD EVALUATION

Hazard evaluation involves a measurement of the quantity available for absorption by the user, the amount of time available for absorption, the frequency with which the exposure occurs, the physical form of the substances, toxicological properties and potency, and the presence of other substances (toxic or nontoxic), additives, or contaminants.

Ventilation, appropriate hygienic practices, housekeeping, protective clothing, and pertinent training for safe handling may eliminate or reduce hazards that might exist.

Hazard evaluation is performed by engineers, chemists, industrial hygienists, toxicologists, and physicians trained in toxicology, industrial hygiene, and occupational medicine who strive to recognize, measure, and control these hazards.

NIOSH/OSHA Standards

Since the passage of the OSHAct, both NIOSH and OSHA have been committed to establishing permissible standards for the workplace that are far more complete than the TLVs® issued by the ACGIH.

A complete substance-specific standard includes the exposure limit of the substance that has been determined to provide a safe, healthful work environment; the methods for collecting, sampling, and analyzing the substance; the engineering controls necessary for maintaining a safe environment; appropriate equipment and clothing for safe handling of the substance; emergency procedures in the event of an accident; medical surveillance procedures necessary for the detection of illness or injury from inadvertent overexposure; and the use of signs and labels to identify hazardous substances.

NIOSH CRITERIA DOCUMENTS

Except in the case of emergency standards, the normal first step in the standard-setting process is the creation of a criteria document for the substance by NIOSH. Such documents are forwarded to OSHA for consideration as permanent OSHA standards.

NIOSH also develops recommended exposure limits (RELs) for hazardous substances in the workplace. Unless noted otherwise, RELs are time-weighted average (TWA) concentrations for up to a 10-hour workday during a 40-hour workweek. RELs are published in NIOSH criteria documents along with appropriate measures to prevent adverse health effects.

NIOSH criteria documents incorporate animal and human data, when available, on carcinogenicity, mutagenicity, teratogenicity, and effects on reproduction. When possible, attempts are made to correlate these adverse reactions with exposures and effects.

Current Intelligence Bulletins (CIBs) are issued by NIOSH for more rapid dissemination of new scientific information about occupational hazards. A CIB may draw attention to a hazard previously unrecognized or may report new data suggesting that a known hazard is either more or less dangerous than was previously thought (see Bibliography).

OSHA STANDARDS

The U.S. Secretary of Labor is responsible for promulgating standards. In some cases, a recommended standard is referred to an advisory committee for study and review in accordance with provisions of the act. OSHA standards are adopted at after extensive review including public hearings. Regardless of the status of the proposed standards in the criteria documents, these documents constitute valuable and readily available sources of information and should be consulted whenever there is interest in a substance for which a criteria document has been written.

Although the standard-setting process is extremely thorough, it is also lengthy and very costly, and has resulted in the promulgation of relatively few regulations (permanent standards).

ACGIH THRESHOLD LIMIT VALUES—TLVS®

In addition to regulated PELs established and enforced by OSHA, many voluntary guides for exposure to airborne contaminants have been proposed. The most widely followed or referenced are those issued annually by the American Conference of Governmental Industrial Hygienists (ACGIH), and are termed Threshold Limit Values (TLVs).

The ACGIH TLVs® are not recommendations of a government agency, but are the product of a committee whose members are associated with government or academia.

Appendix B presents the *2001 Threshold Limit Values* (*TLVs®*) *for Chemical Substances and Physical Agents and the Biological Exposure Indices* (*BEIs®*), reprinted with permission. This information is also available directly from the American Conference of Governmental Industrial Hygienists, Inc. (ACGIH®)

The *Threshold Limit Values* (*TLVs®*) *for Chemical Substances and Physical Agents and the Biological Exposure Indices* (*BEIs®*) book is published annually by the ACGIH and is available for a nominal cost. It is copyrighted by the ACGIH and is reproduced here with permission. For information about this publication, contact ACGIH at Kemper Meadow Center, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634, (513) 742-3355, http:www.acgih.org; e-mail: mail@acgih.org.

Limitations of TLVs®

The TLV Committee intended the TLVs® they issued to be used as *guides* in the control of health hazards, *not as fine lines between safe and dangerous concentrations*. The committee noted many reasons for the inadequacy of these numbers for such purposes. Despite this admonition, however, the TLV list gradually became incorporated into many state and federal regulations. Because the basic concepts underlying exposure and measurement are the same for TLVs and regulated PELs, it is worth examining the nature of TLVs in some detail.

One of the fundamental tasks confronting the industrial hygienist is assessing the possible degrees of exposure to a variety of substances in the work environment. It is accepted that there is a threshold level (exposure) for almost all substances below which no measurable impairment of health occurs. Because the most common route of entry for a chemical in the workplace is inhalation, the practice for many years has been to sample the air being breathed by the workers and compare the result with a suitable standard.

Although air standards and guides such as those developed by OSHA, ACGIH, and NIOSH are most widely used in industrial hygiene practice, certain shortcomings are inherent in any air standard. This limits their applicability to some situations. Some of the more common recognized problems include the following:

1. Difficulty in acquiring a truly representative breathing zone sample
2. Uncertainties about the extent of absorption of the amount inhaled
3. Nonroutine or nonrepetitive work; air samples can characterize work operations only on the day the sample is taken
4. Variations in particle size, absorption, and particle solubility
5. Accidental or deliberate contamination of sample

The TLV list is basically an alphabetical listing of substances with the recommended limits expressed either in parts per million by volume or milligrams per cubic meter; see Appendix B. It is the practice to express the TLV for all substances expected to be present in the air as particulate suspensions in milligrams per cubic meter. For substances expected to be present as gases or vapors, the TLV is expressed in parts per million, and for convenience the equivalence in milligrams per cubic meter is also presented.

Formulas are available for determining TLVs® for the inhalable-thoracic and respirable-particulate fractions, obtained by means of a suitable particle-size–discriminating device. The asbestos TLV is unique, and is expressed in fibers per cubic centimeter of air.

Time-Weighted Average

It is implicit in all TLVs® that measurements are made in the breathing zone of a worker and are obtained in such a way that a TWA can be calculated. In general, for an eight-hour workday,

$$\text{TWA} = \frac{C_a T_a + C_b T_b + \ldots\ C_n T_n}{8}$$

where T is the time of exposure period and C is the concentration of contaminant during that period. This concept has proven to be a useful means of estimating the long-term chronic effects of exposure to most substances in the workplace. Although the TWA does not necessarily predict the amount of a substance that will be absorbed, it does measure the amount that can be inhaled during a workday; considerations of the extent of absorption aid in the selection of a value that affords the desired degree of protection.

It is inherent in the definition of a TWA that concentrations higher than the recommended value can be permitted for some periods of time as long as these levels are offset by periods of lesser concentration. The degree of permissible excursion is related to the TLV of the substance. The relationship between threshold limit and permissible excursion is a general rule that may not apply in certain cases (Figure 6–4).

Ceiling Values

For some substances, it is not advisable to permit concentrations substantially above the recommended TWA; the TLV committee designates these substances with the letter *C,* which stands for *ceiling value*. Most substances designated with a C tend to be irritants for which a TLV has been set slightly below the level where irritation will be noticed by the most sensitive individuals. *Exposures should never exceed the ceiling value.*

The durations of sampling necessary to determine whether the exposures are within the limits for each group usually differ. A single brief sample that is applicable to a C limit is not appropriate for calculating a TWA.

The TLV list also contains another listing of values for many substances that are called short-term exposure limits (STELs).

Mixtures

When two or more hazardous substances that act on the same body organ system are present, their combined effect, rather than that of either component, should be given primary consideration. In the absence of information to the contrary, the effects of the different hazards should be con-

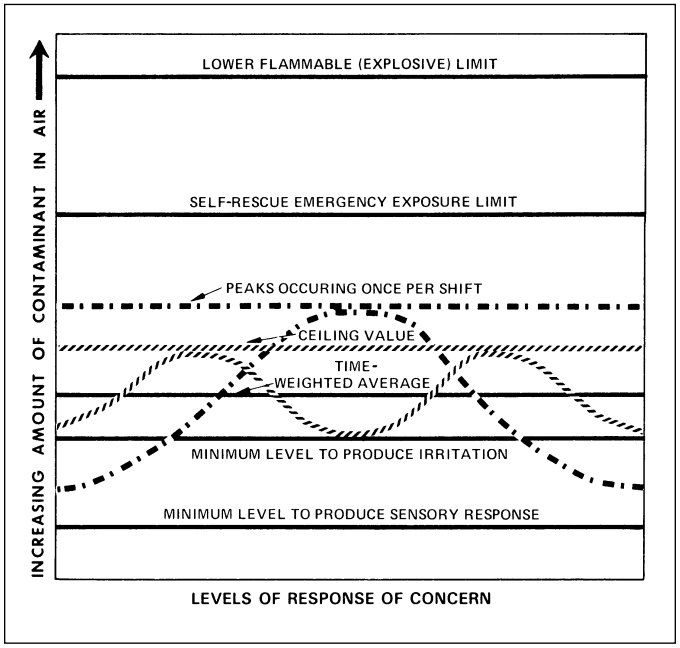


Figure 6–4. Knowledge of the type of injury that would result from exposure to various contaminant levels is important to health and safety professionals.

sidered additive. Exceptions can be made when there is a good reason to believe that the chief effects of the different harmful substances are independent, as when purely local effects on different organs of the body are produced by the various components of the mixture.

The formula for additive effects is as follows:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \ldots = 1$$

where C = the observed atmospheric concentration
T = the corresponding Threshold Limit Value

If the sum of the fractions is greater than one, then the Threshold Limit Value has been exceeded.

Antagonistic action or potentiation may occur with some combinations of contaminants. At present, such cases must be determined individually. Potentiating or antagonistic agents may not necessarily be harmful by themselves. Potentiating effects of exposure by routes other than that of inhalation are also possible, such as the effect of ingested alcohol on an inhaled narcotic (trichloroethylene).

When a given operation or process emits a number of harmful dusts, fumes, vapors, or gases, it is often feasible to attempt to evaluate the hazard by measuring a single (surrogate) substance. In such cases, the threshold limit used for this substance should be reduced by a suitable factor, the magnitude of which depends on the number, toxicity, and relative quantity of the other contaminants ordinarily present.

Examples of processes that are typically associated with multiple harmful atmospheric contaminants are welding, automobile repair, painting, reinforced plastic fabrication, shipbuilding, biotechnology, and chemical manufacturing.

Carcinogens

Because causal mechanisms and dose-response relationships are not well understood for many carcinogens, the ACGIH considers them separately in the TLV® booklet. It rates substances based on the quality and weight of data available which assesses a substance's carcinogenic potential.

If no data are available for a particular substance, no rating is assigned. The ratings are as follows:

- A1—Confirmed Human Carcinogen
- A2—Suspected Human Carcinogen
- A3—Confirmed Animal Carcinogen With Unknown Relevance to Humans
- A4—Not Classifiable as a Human Carcinogen
- A5—Not Suspected as a Human Carcinogen

(See Appendix B, for definitions of these ratings of the carcinogenicity of substances.)

Physical Factors

It is recognized that such physical factors as heat, ultraviolet and ionizing radiation, and work under high atmospheric pressure or at a high altitude cause adverse health effects following sufficient exposure. Certain physical stresses may also alter the response to a toxic substance. Although most threshold limits have built-in safety factors to guard against moderate deviations from normal environments, the safety factors of most substances are not large enough to account for gross deviations. For example, continuous work at temperatures above 32 C (90 F) or work at altitudes above 3,000 m would be considered gross deviations. In such instances, judgment must be exercised in the proper downward adjustments of the TLVs®.

Unlisted Substances

Many substances used or created (including by-products) in industrial processes do not appear on the TLV list. For many, the committee does not have sufficient information from which to derive a TLV, even on a tentative basis. Also, some substances of considerable toxicity have been omitted primarily because only a limited number of workers, such as employees of a single plant, have potential exposure to possibly harmful concentrations.

Basic Data Used for TLVs®

If possible, the ACGIH TLV committee selects a value based on human experience. Epidemiological studies, which include environmental data and morbidity and mortality data, are the best possible basis for a TLV, but in most cases, such studies do not exist. In the absence of epidemiological studies, individual cases involving human exposures are considered, but usually the most useful literature available is from animal toxicological studies. The preferred studies for determining acceptable exposure limits are those based on long-term inhalation tests involving several animal species at concentrations both above and below the lowest effect level.

However, scientists often must rely on short-term inhalation data or, in many cases, toxicity studies in which the substance was introduced into the experimental animals by routes other than inhalation. The least useful toxicological data are those based on short-term oral intake, intended to measure the acute toxicity, or the ability of the substance to kill the exposed animals. It is not surprising, therefore, that the publication of new information often results in dramatic changes in some TLVs®.

Documentation

The policy of the TLV committee is to prepare a justification for each proposed TLV. These are published in a document titled *Documentation of Threshold Limit Values,* available from the ACGIH (see Bibliography). In these documents, the principal data that the committee considered significant are reviewed and references are cited. The justification and documentation are discussed in the following categories:

- chemical and physical properties
- occupational exposure
- animal studies
- reproductive and developmental studies
- genotoxicity studies
- pharmacokinetic/metobolism studies
- human studies

Table 6–H. *Classification of Criteria for ACGIH TLVs® Applicable to Humans and Animals**

Applied Criteria			
Morphologic	*Functional*	*Biochemical*	*Miscellaneous*
Systems or organs affected: lung, liver, kidney, blood, skin, eye, bone, CNS, endocrine, exocrine, reproductive	Changes in organ function: lung, liver, kidney, reproductive	Changes in amounts of biochemical constituents, including hematologic	Nuisance:
Carcinogenesis	Irritation	Changes in enzyme activity	Visibility
Roentgenographic changes	Mucous membranes (epithelial linings, eye, and skin)	Immunochemical allergic sensitization	Cosmetic
	Narcosis	Hormone activity	Comfort
	Odor		Aesthetic
			(Analogy)
Potentially Useful Criteria			
Altered reproduction	Behavioral changes:	Radiomimetic effects	
Body-weight changes	Cerebral functions	Teratogenesis	
Organ/body weight changes	Conditioned and unconditioned reflexes—learning	Mutagenesis/Genotoxicity	
Food consumption	Audible and visual responses		
	Endocrine glands		
	Exocrine glands		

* Adapted from Stokinger, H.E. Criteria and procedures for assessing the toxic responses to industrial chemicals. Permissible Levels of Toxic Substances in the Working Environment, Occupational Safety and Health, ser. 20. Geneva, Switzerland: International Labor Office, 1970.

- ➢ TLV® recommendation
- ➢ other recommendations
- ➢ carcinogenic classification
- ➢ TLVs of other nations
- ➢ references

This document should be consulted whenever a particular TLV is to be applied, for it is important to be aware of the basis for each standard. In most cases, a particular value is selected on the basis of one or more of the consequences of overexposure listed in Table 6–H.

One of the advantages of the TLV list is its relative timeliness. The list contains a section titled "Notice of Intended Changes"; as the name suggests, all changes, including additions, are listed for a period of at least two years. During this period, the TLV committee solicits comments from interested parties concerning the suggested changes. By comparison, OSHA PELs and substance-specific standards usually require many years for adoption or change—if at all.

Threshold Limit Values® are intended only for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential health hazards. The TLVs® should be interpreted and applied only by a person trained in industrial hygiene. They are not intended for use, or for modification for use, as a relative index of hazard or toxicity, in the evaluation or control of community air pollution nuisances, in estimating the toxic potential of continuous, uninterrupted exposures or other extended work periods, as proof or disproof of an existing disease or physical condition, or for adoption by countries in which working conditions differ from those in the United States and where substances and processes differ. These limits are not fine lines between safe and dangerous concentrations. See Chapter 15, Evaluation, for further discussion of the use of TLVs®.

BIOLOGICAL TESTING

A useful means of assessing occupational exposure to a harmful material is the analysis of biological samples obtained from exposed workers. Biological sampling, however, should not be considered a substitute for air sampling. Ethical considerations prohibit what some have called the use of the worker as an "integrated air-sampling device." Biological analysis may provide an indication of the body burden of the substance, the amount circulating in the blood, or the amount being excreted. Virtually every tissue and fluid in the body can be analyzed, but for practical reasons, most bioassays are confined to specimens of urine or blood. For substances such as carbon monoxide and many solvents, the analysis of exhaled breath samples indicates the level of previous exposure. Occasionally, analysis of samples of hair, nails, feces, or other tissues may be useful.

Whereas air monitoring measures the composition of the external environment surrounding the worker, biological monitoring measures the amount of chemical absorbed via any route (lungs, skin, mucosa, etc.) are measured. In addition, the effects of added stress (such as increased work load resulting in a higher respiration rate with increased intake of the air contaminant) are reflected in the results. The total exposure (both on and off the job) to harmful materials is included.

For some chemicals, biological assays, in addition to air measurements, can be much more reliable indicators of health risks than measurements of air contaminants alone (Table 6–I).

Analyses that can be performed on biological samples include the following:

- ➢ Analysis for the unchanged substance (such as lead, arsenic, mercury) in body fluids and tissues

Table 6–I. ***Body Tissues and Fluids Suitable for Biological Analysis***

Analysis of Urine Samples May Be Useful for the Following Compounds		
Acetone	2-ethoxyethanol acetate (2-ethoxyacetic acid)	Pentachlorophenol
Aluminum	Ethyl benzene (mandelic acid)	Phenol
Aniline	Fluoride/Hydrogen fluoride	Selenium
Antimony	Furfural (furoic acid)	Styrene (mandelic acid)
Arsenic/ Arsine	N-hexane (2-5-hexanedione)	Tellurium
Benzene (phenol)	Hydrogen cyanide	Tetrachloroethylene (trichloroacetic acid)
Benzidine	Isopropyl alcohol (acetone)	Tetrahydrofuran
Cadmium	Lead	Thallium
Carbon disulfide (2-thiothiazolidine-4-carboxylic acid)	Manganese	Toluene (hippuric acid)
Chlorinated benzene (4-chlorocatectol)	Mercury	1,1,1-trichloroethane (trichloroacetic acid, trichloroethanol)
Chromium H_20-soluble compounds	Methanol (or formic acid)	Trichloroethylene (trichloroacetic acid, trichloroethanol)
Cobalt	Methyl ethyl ketone	Triethylamine (triethylamic and TEA n-oxide)
Cyanide (thiocyanate)	Methyl isobutyl ketone	Uranium
Cyclohexane (cyclohexanol)	Nickel	Vanadium pentoxide
Dichloromethane	Nickel carbonyl (nickel)	Xylene (methyl hippuric acid)
Dimethylacetamide (methylacetamide)	Nitrobenzene (p-nitrophenol)	Zinc
Dimethyl formamide (N-methylformamide)	Parathion (nitrophenol)	
2-ethoxyethanol (2-ethoxyacetic acid)		
Analysis of Blood Samples May Be Useful for the Following Compounds:		
Acetone	Cyclohexane	Pentachlorophenol
Aniline (methemoglobin)	Dichloromethane (carboxyhemoglobin)	Styrene
Cadmium dust, fume	Ethylene oxide	Tetrachloroethylene
Carbon monoxide (carboxyhemoglobin)	Lead	Toluene
Cholinesterase inhibitors (RBC cholinesterase)	Manganese	Trichloroethylene (or trichloroethanol)
Cobalt	Mercury	Xylene
	Nitrobenzene (methemoglobin)	
Breath Analysis May Be Useful for the Following:		
Benzene	N-hexane	1,1,1-thrichloroethane
Dichloromethane	Tetrachloroethylene	Trichloroethylene
Ethyl benzene		

* Note: Metabolites are given in parentheses where they are the best indicators of exposure and absorption of a compound.

- ➢ Analysis for a metabolite of the substance in body fluids or tissues, such as phenol in urine resulting from exposure to benzene
- ➢ Analysis to determine the variations in the level of a naturally occurring enzyme or other biochemical substance normally present in body fluids or tissues, such as depression of cholinesterase activity as a result of exposure to organic phosphate compounds

The rates of absorption, metabolism, and excretion for a particular substance determine when it is most appropriate to analyze samples in relation to duration and time of exposure. For rapidly excreted or exhaled substances, peak concentrations are found during or immediately after exposure. Peak excretion rates for metabolites of some organic solvents and some inorganic substances may occur minutes to hours after exposure. Biological levels of metals with cumulative properties (such as lead or mercury) may reflect the response to several days' or weeks' prior exposure. The "half-lives" of various chemicals in the body have been established and are an important consideration in biological testing for exposure.

People with virtually identical exposure histories can show a wide variation in response due to subtle differences in their rates of absorption, tissue storage, or metabolism. Greater significance should be given to the variations in an individual's level from period to period than to the variations between different individuals within a group.

Some harmful substances can be stored for long periods of time in various parts of the body. The substances are unlikely to be evenly distributed throughout the body. In many cases, the organ with the highest concentration of the material is the liver or kidney.

Many materials, including organic compounds, undergo detoxification in the body. The body converts the material to something else that may reduce its ability to cause injury. Occasionally, the conversion enhances the toxicity, but in any event, the process helps the body to dispose of the material. The conversion products may appear in the urine or blood as metabolites (see Table 6–I).

Many organic chemicals of high molecular weight and low vapor pressure are not found in workroom air at elevated concentrations under normal conditions of work, but the same substances can be absorbed through the intact skin, giving rise to excessive absorption that cannot be measured by air sampling. In such cases, a suitable biological analysis

can be an excellent means of detecting the failure of skin-protection measures.

For a few regulated substances, OSHA has set biological limits (e.g., blood lead). For many others, the ACGIH has adopted a set of advisory biological limit values called the Biological Exposure Indices (BEIs®). These indices use urine, blood, or expired air sampled under strictly defined conditions. The user should become familiar with the extensive documentation that accompanies these indices in the ACGIH *Documentation of Threshold Limit Values* (2001) and *Threshold Limit Values® for Chemical Substances and Physical Agents and Biological Exposure Indices®* (2001). (See Chapter 15, Evaluation, for a more detailed discussion of Biological Exposure Indices.)

Because the collection of blood, urine, or breath samples requires the use of medical personnel, most programs of biological monitoring become a cooperative effort between the safety, industrial hygiene, and medical departments.

The analysis and interpretation of biological samples is obviously of great importance and because the quantities involved are almost always very slight, great care must be taken in performing such analyses. Ordinarily, existing plant laboratories are not equipped or trained to perform these analyses in a satisfactory manner, and it is advisable to use a laboratory that has proven capability in this area.

Urine, Blood, and Breath Analyses

Tests for the level of metabolites of toxic agents in the urine, blood, and breath have found wide use in industrial toxicology as a means of evaluating exposure of workers. The concentration of the metabolic product is related to the exposure level of the toxic agent. Because normal values of such metabolites have been established, an increase above normal levels indicates that an overexposure has occurred. This provides a valuable screening mechanism for estimating the hazard from continued or excessive exposure. Because lead, for example, interferes with porphyrin metabolism, erythrocyte protoporphyrin can be a useful measure and the results are useful as an indicator of lead effect (and absorption).

One of the best documented examples of the effectiveness of biological sampling is that of analysis for exposure to lead and its compounds. It is almost universally agreed that the level of lead in the blood is the best index of the probability of damage resulting from lead exposure.

For many other substances there is no known biological test as useful as the measurement of lead in blood, whereas for other substances the correlation between bioassay tests and symptoms is so poor as to render a biological analysis of little value. The aim of an industrial hygienist or safety professional is to control exposure to harmful materials; both air sampling and biological monitoring contribute valuable information regarding exposure and health impact.

The industrial hygienist or safety professional is charged with maintaining a safe, healthful environment and should probably do air sampling; indeed, it is required by law in many cases.Where available and indicated by exposure risk, biological testing may also be required or appropriate.

If inhaled gases and vapors are fat-soluble and are not metabolized, they are cleared from the body primarily through the respiratory system. Examples of these are the volatile halogenated hydrocarbons; the volatile aliphatic, olefinic, and aromatic hydrocarbons; some volatile aliphatic saturated ketones and ethers; esters of low molecular weight; and certain other organic solvents such as carbon disulfide.

For industrial solvents that continue clearing from the body in exhaled breath for several hours after exposure, analysis of progressive decrease in the rate of excretion in the breath can be very helpful in showing not only the nature of the substances to which the worker was exposed, but also the magnitude of the exposure and probable blood levels. By use of gas chromatography or infrared analysis of breath samples, the identification of the substance can be established, permitting comparison of the exposed workers' breath decay rate with worker's published excretion curves. There is, however, considerable individual variation and it is not easy to set standard values.

SOURCES OF TOXICOLOGAL INFORMATION

The health and safety professional can turn to several sources for information when a question arises about the toxicity and hazard of a material.

Material Safety Data Sheet

Material Safety Data Sheets (MSDSs) are a prime source of information on the hazardous properties of chemical products, although the quality of such information is highly variable. The OSHA Hazard Communication Standard requires that all chemical manufacturers and importers supply an appropriate MSDS to their customers. The MSDS is usually developed by the chemical manufacturer. Additionally, all users of the product (employers) must have an MSDS for every hazardous chemical used in the workplace.

Although OSHA does not specify the format of the MSDS, it does require certain specific information. A sample form approved by OSHA for compliance with the Hazard Communication Standard is shown in Figure 6–5.

There are eight categories of information on the MSDS:

SECTION I

Name and address of the manufacturer (the originator of the MSDS)

- ➢ Emergency telephone number, which can be used to contact a "responsible party" for information about the product
- ➢ Information telephone number, to be used in non-emergency cases to contact the manufacturer
- ➢ Signature of the person responsible for the MSDS and the date it was developed or revised

Material Safety Data Sheet

May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*	*Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.*

Section I

Manufacturer's Name	Emergency Telephone Number
Address *(Number, Street, City, State, and ZIP Code)*	Telephone Number for Information
	Date Prepared
	Signature of Preparer *(optional)*

Section II — Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% *(optional)*

Section III — Physical/Chemical Characteristics

Boiling Point		Specific Gravity (H_2O = 1)	
Vapor Pressure (mm Hg.)		Melting Point	
Vapor Density (AIR = 1)		Evaporation Rate (Butyl Acetate = 1)	

Solubility in Water

Appearance and Odor

Section IV — Fire and Explosion Hazard Data

Flash Point (Method Used)	Flammable Limits	LEL	UEL

Extinguishing Media

Special Fire Fighting Procedures

Unusual Fire and Explosion Hazards

(Reproduce locally) OSHA 174, Sept. 1985

Figure 6–5. Material Safety Data Sheet (Continues)

Section V — Reactivity Data

Stability	Unstable		Conditions to Avoid
	Stable		

Incompatibility (*Materials to Avoid*)

Hazardous Decomposition or Byproducts

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur		

Section VI — Health Hazard Data

Route(s) of Entry: Inhalation? Skin? Ingestion?

Health Hazards (*Acute and Chronic*)

Carcinogenicity: NTP? IARC Monographs? OSHA Regulated?

Signs and Symptoms of Exposure

Medical Conditions
Generally Aggravated by Exposure

Emergency and First Aid Procedures

Section VII — Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled

Waste Disposal Method

Precautions to Be Taken in Handling and Storing

Other Precautions

Section VIII — Control Measures

Respiratory Protection (*Specify Type*)

Ventilation	Local Exhaust	Special
	Mechanical (*General*)	Other

Protective Gloves	Eye Protection

Other Protective Clothing or Equipment

Work/Hygienic Practices

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★ USGPO 1986-491-529/45775

Figure 6–5. (Concluded)

SECTION II: HAZARDOUS INGREDIENTS

- ➢ Common name used as identification on the label (the code name or number, trade, brand, or generic name)
- ➢ Chemical name: the scientific designation of a chemical in accordance with the nomenclature systems of the International Union of Pure and Applied Chemistry (IUPAC) or the Chemical Abstracts Service (CAS)
- ➢ CAS number: the identification number that is unique to a particular chemical and is assigned by the Chemical Abstracts Service

SECTION III: PHYSICAL AND CHEMICAL CHARACTERISTICS

- ➢ Physical and chemical data such as boiling point, vapor pressure, vapor density, solubility appearance, melting point, and evaporation rate

SECTION IV: FIRE AND EXPLOSION HAZARD DATA

- ➢ Information needed for planning fire and explosion prevention, including flash point, flammable limits, and special fire-fighting procedures

SECTION V: REACTIVITY DATA

- ➢ Outline of the stability of the product and the potential for hazardous polymerization and decomposition and a list of materials and conditions to avoid during use

SECTION VI: HEALTH HAZARDS

- ➢ Explanation of the most common sensations or symptoms a person might experience from acute and chronic *overexposure* to the material or its components, emergency and first aid procedures, any TLVs® or PELs are listed, and, if the chemical is a carcinogen, the source of this designation

SECTION VII: SAFE HANDLING AND USE

- ➢ Designated special handling and disposal methods and storage and spill precautions

SECTION VIII: CONTROL MEASURES

- ➢ Manufacturer recommendations for the use of ventilation, personal protective equipment, and hygienic practices

Many data sheets now also contain detailed information regarding labeling, transport, toxicity, and regulatory requirements. All required sections must be completed. If the required information is not available or not applicable, this must be shown on the form. Additionally, if the ingredients of a chemical mixture are trade secrets, their identity can be withheld, but their hazardous properties must be given.

These forms are required to be readily available to employees. Training in their use should be included in employee training required under the Hazard Communication legislation (see Chapter 28, Government Regulations).

Information Resources

The Internet now provides immediate access to current toxicology data and hazardous substance information. For all but the most common and well-studied substances (e.g., acetone, sodium hydroxide), reliable databases (Internet-accessible) should be queried first for relevant data and guidelines. However, beware of data obtained from websites, the authors of which are not listed and/or are not a government agency or academic institution.

Listed below are recommended websites—all with search capabilities.

MSDS LIBRARIES

1. Cornell University http://msds.pdc.cornell.edu/issearch/msdssearch.htm
2. University of Vermont http://hazard.com/msds/index.html

TOXICOLOGY

1. Occupational Health Guidelines to Chemical Substances (NIOSH—summaries) http://www.cdc.gov/niosh/chem-inx.html
2. TOXNET http//toxnet.nlm.nih.gov/servlets/simplesearch?1.4.1.6994 Useful databases include: Hazardous Substance Data Bank, Gene-Tox (mutagenicity data) and Reproductive databases
3. Reproductive database—"DART" http:toxnet.nlm.nih.gov/servlets/simple-search?1.25.0.6994
4. National Toxicology Program http://ntp-server.niehs.nih.gov/

a) NTP Report on Carcinogens http://ehis.niehs.nih.gov/roc/

5. Medicine and toxicology Internet Grateful Med (Carcinogens) http://igm.nlm.nih.gov/ Useful databases: Medline, ChemID, Toxline
6. IARC (International Agency for Research on Cancer)—substance-specific data summaries and analyses http://193.51.164.11
7. TOMES (proprietary toxicology database) http://www.micromedex.com

PUBLIC HEALTH—CENTERS FOR DISEASE CONTROL AND PREVENTION HTTP:/WWW.CDC.GOV

REGULATORY

1. OSHA—home page http://www.osha.gov
2. EPA—home page http://www.epa.gov
3. European Union European Agency for Safety and Health at Work http://europe.osha.eu.int/

ORGANIZATIONS

1. American Conference of Governmental Industrial Hygienists (ACGIH) http://www.acgih.org
2. American Industrial Hygiene Association http://www.aiha.org
3. American National Standards Institute http://www.ansi.org

4. American Society of Safety Engineers http://www.asse.org
5. National Safety Council http://www.nsc.org
6. National Institute for Occupational Safety and Health (NIOSH) http:\\www.cdc.gov/niosh
7. World Health Organization http://www.who.org
8. U.S. Government Printing Office http://www.access.gpo.gov/
   Phone: (202) 512-1800
   Fax: (202) 512-2250

SUMMARY

The word *toxicity* is used to describe the ability of a substance to have an adverse effect on the health or well-being of a human. Whether any ill effects occur depends on the properties of the chemical, the dose (the amount of the chemical acting on the body or system), the route by which the substance enters the body, and the susceptibility or resistance of the exposed individual.

There are four routes of entry or means by which a substance may enter or act on the body: inhalation, skin absorption or contact, ingestion, and injection. Of these, inhalation is the most important occupational exposure route.

When a toxic chemical acts on the human body, the nature and extent of the injurious response depends on the dose received—that is, the amount of the chemical that actually enters the body or system and the time interval during which this dose is administered. Response can vary widely and might be as slight as a cough or mild respiratory irritation or as serious as cancer and death.

The practice of industrial hygiene is based on the concept that for each substance there is a level of exposure below which significant injury, illness, or discomfort rarely or never occurs. The industrial hygienist protects the health of workers by assessing potential chemical and physical agent exposures and controlling the environmental conditions so that the risk of exposure is minimized.

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Chapter 7

Gases, Vapors, and Solvents

by George P. Fulton, MS, CIH
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A potential threat to the health, productivity, and efficiency of workers in most occupations and industries is their exposure to gases and vapors from solvents, chemical products, by-products of chemical use, and chemical processes. No one fully comprehends the total effect, yet all of us are exposed and we all are affected.

Exposures to volatile chemicals occur throughout life, from conception to death. For example, organic solvent vapors inhaled by a mother can reach the fetus. Exposures also occur in the course of daily living, ranging from the inhalation of vapors from a newspaper freshly off the press, to exposure to cleaning solvents by all routes of entry, to a worker manufacturing computer chips, to a researcher in a laboratory, to a farm worker hoeing weeds. It may occur at home or at work. Effects from the exposure may range from a simple objection to an odor to death at high concentrations. In between, there is a whole spectrum of effects.

Solvents convert substances into a form suitable for a particular use. Solvents are significant because many substances are most useful when in solution.

Organic and inorganic compounds are used in the home as cleaning agents, paint thinners, coatings, and spot removers; in the office as typewriter key cleaners, desktop cleaners, and wax removers; in commercial laundries as dry cleaning liquids; on the farm as pesticides; in laboratories as chemical reagents and drying, cleaning, and liquid extraction agents; in shops as cleaners, solvents, by-products from processes such as welding, and paints. Many consumer products packaged in cans and drums contain mixtures of organic chemicals.

Because of the nearly infinite number of combinations possible for the variables involved—hundreds of different compounds, degree of concentration, duration of exposure, combined effects with other solvents, gases and vapors, and the health and age of an exposed person—generalizations about effects of exposure on a particular person are difficult to make. The problem lies not so much in the effect itself, but rather in determining which effects are harmful and at what level.

PROPERTIES OF GASES, VAPORS, AND SOLVENTS

Two of the three fundamental states of matter, gases and liquids, are discussed in this chapter; the solid phase is discussed in the next chapter. A gas is a formless fluid that completely fills its container and that exerts an equal pressure in all directions. Gases spread rapidly throughout a room by diffusion.

Gases are materials that are in the gaseous state at normal temperature (25 C) and pressure (1 atmosphere)—NTP. Chemicals that are liquids at NTP will exist partially in the gaseous phase, and that portion is known as a vapor. If a liquid is spilled, or otherwise has a large surface area, some will evaporate, and, over time, equilibrium may be established between the gas and liquid phases. The vapor pressure is a measure of the concentration of the chemical in the air at equilibrium; the higher the vapor pressure, the higher the concentration of the chemical at equilibrium. Vapor pressure is very temperature dependent, so that as the temperature rises, the airborne concentration of an equilibrium mixture will rise. Although there is often insufficient time or material for equilibrium to be established, the vapor pressure remains a good measure of the tendency of a liquid to evaporate, and, other factors being equal, a solvent with a higher vapor pressure will have a higher airborne concentration than a solvent with a lower vapor pressure.

Solvents are liquids in which something, called a solute, can be dissolved; solids may also be suspended in solvents. The solute may have been a solid, a gas, or another liquid before being dissolved in the solvent. Solvents are very useful both to transport solutes and to clean materials. In many cases, such as paint application, solvents work best if they evaporate relatively quickly, leaving behind an even application of the solid material; however, this very property may lead to high vapor concentrations in the air.

Although the term "solvent" is often used to describe organic solvents, water is a solvent as well. Common acids and bases are aqueous solutions. The common inorganic acids include the hydrogen halides (HF, HCl, HI, HBr), the oxygen acids (nitric [HNO_3], phosphoric [H_3PO_4], and sulfuric [H_2SO_4]), and others such as hydrogen sulfide (H_2S) and hydrogen cyanide (HCN). These are commercially available as compressed gases, liquids, aqueous solutions of various concentrations, or, in some cases, as solids. These acids may be strong (completely ionized in aqueous solution) or weak (parent acid in equilibrium with its acid anion; the parent acid predominates).

Vapor phase water is not considered hazardous, and the solutes that dissolve in water are polar or ionic, and so generally have low vapor pressures; therefore, there is less potential hazard from inhalation of vapors from aqueous solutions in general. However, the gases that dissolve in water to form acids will off-gas from solution due to the equilibrium between the gas phase and the solution. The more volatile acids, such as HCl, do so readily; the less volatile acids, such as H_2SO_4 and H_3PO_4, do so only at elevated temperatures. As temperatures are increased, equilibrium is driven to the gas phase; the simple acids are driven off as the gas and the oxygen acids can decompose to produce oxides such as NO/NO_2 and SO_2/SO_3. As the pH is lowered (more acidic), volatility from solution is increased; as the pH is raised (more alkaline), the acid anion is stabilized in solution and it is essentially not volatile.

Another important characteristic of solvents, in addition to their volatility, is their polarity. Some solvents are highly polar, like water, while others are nonpolar, such as hexane, and others are of intermediate polarity. A fundamental principle, "like dissolves like," states that more polar or ionic solutes will dissolve more readily in polar solvents than in nonpolar solvents. For example, more salt will dissolve in water than in hexane, that is, salt is more soluble in water than in hexane. Conversely, grease dissolves better in gasoline than in water.

Solubility is very important in understanding the hazards presented by various solvents as solubility affects absorption into the body, distribution throughout the body, storage in various tissues, and elimination of chemicals. Thus, more fat soluble, or lipophilic, chemicals pass through the skin than those chemicals that are soluble in water only, while substances that are soluble in both water and fat are most readily absorbed. Clearly dermal absorption will be more important for the latter compounds. Solubility is also important in evaluating the potential effect of a chemical on the central nervous system. The blood-brain barrier appears to be much more effective at excluding ionized molecules than those that are fat soluble. Water soluble compounds tend to be excreted fairly rapidly, while fat soluble substances are often stored in the adipose tissue.

Where a solvent system is in use, three distinct possible routes of exposure must be considered. First, if an opportunity exists for skin contact, dermal absorption may be important. If the vapor pressure is high, or the temperature is high, inhalation of vapors may be important. Finally, one must also consider the possibility of exposure to an aerosolized mist of the solution, in which case there is also exposure to the solutes. Because of the high volume of breathing and the large surface area of the lungs, which are designed for maximum interchange between blood and air in the lungs, inhalation is usually the most important route of exposure. However, in some cases the dermal route predominates.

CRITICAL EXPOSURE FACTORS

The hazard presented by use of a chemical is a function not only of its inherent toxicity, but also of the potential for exposure. While one substance may be extremely toxic, and therefore very well controlled so that the exposure is negligible, a greater hazard may then exist in the same workplace due to an inherently less toxic chemical which is totally uncontrolled, and to which the worker is exposed at high levels.

Mode of Use and Potential for Exposure

The most important factors in exposure potential are how the material is used and what controls (engineering or personal protective equipment), if any, are in place. Processes that use gaseous reactants (as in a semiconductor chip manufacturing process) are often completely enclosed; the gases are often too reactive to coexist with air and the purity of the product demands it. In the event of a system failure, a compressed gas at pressures of several hundred pounds per square inch (psi) poses greater risk than a liquefied gas with a pressure of a few psi. Painting operations pose risk of exposure to solvents, reactive chemicals such as the isocyanates, or suspected carcinogens such as hexavalent chromium (used in primers). Spray painting poses a greater exposure risk for the worker than brush or roller application. When inhalation exposures are controlled, dermal exposure may be the major route of entry. Many organics readily permeate the skin or glove materials; some, such as dimethyl sulfoxide, are of limited toxicity but may be a vehicle for transporting other toxic materials into the body.

Temperature and Volatility

The airborne concentration of a solvent vapor depends on the vapor pressure, which is a measure of the volatility of the solvent. The vapor pressure of any chemical compound is directly related to the temperature. For solvents that are liquids at room temperature, this can make a significant difference in exposure potential. For example, methyl ethyl ketone (MEK) has a vapor pressure of 100 mm Hg at 25 C and 400 mm at 60 C. Thus, for two similar processes using the same solvent, the one taking place at lower temperature poses less potential for exposure.

The boiling point and vapor pressure increase with increasing numbers of carbon atoms provided the functional group remains the same; for example, among the three ketones, acetone, methyl ethyl ketone, and methyl isobutyl ketone (3, 4, and 5 carbon atoms, respectively), the boiling points are 56, 80, and 128 C, respectively. However, compounds with the same number of carbon atoms but different functional groups will have very different boiling points and vapor pressures; for example, the compounds with three carbon atoms have boiling points ranging from –44 F for propane (a hydrocarbon), through 133 F for acetone (a ketone), 207 F for propanol (an alcohol), to 256 F for methyl cellosolve, or 2-methoxy ethanol.

Concentration

The effect of concentration may be manifested in several ways. From the point of view of chemical kinetics, reaction rates depend on some factor of concentration; for a given concentration x, the rate is proportional to x, x^2, or some other factor depending on the reaction mechanism. Nitric oxide (NO, TLV 25 ppm) at higher concentrations reacts rapidly with oxygen to produce nitrogen dioxide (NO_2, TLV 3 ppm), but at very low concentrations the rate is very slow. The vapor pressure of a solute over a solution varies directly as the mole fraction (concentration) of the solute and the vapor pressure of the solute when it is pure, according to Raoult's law. In both cases, reducing concentration reduces the potential for exposure by limiting the amount of toxic product formed or volatilized. Some chemicals, such as sulfuric acid, are available in a variety of concentrations; the standard grade is approximately 98 percent acid. The vapor pressure is so low at room temperature that it poses minimal risk. The grade marketed as oleum, or fuming sulfuric acid, is much more reactive and off-gases sulfur dioxide; it poses significant risk to the worker. Chemical protective clothing for those working with highly reactive materials must be selected carefully; butyl rubber is satisfactory for sulfuric acid, but has significantly diminished breakthrough times for oleum.

Reactivity

Chemical reactivity can enhance or reduce health hazard potential. Other physical hazards, such as fire, become significant for pyrophoric materials such as silane (SiH_4) and yellow phosphorus. Acids or bases can react with volatile compounds to stabilize them. In a strongly alkaline solution (high pH), cyanide salts cannot form volatile hydrogen cyanide (HCN); in an acid solution (low pH), volatile amines (ammonia or organic amines) are converted to nonvolatile ammonium salts in solution. Liquid metal halides (tungsten or rhenium hexafluoride) react rapidly with moisture in the air to form gaseous hydrogen fluoride (HF).

Exposure Guidelines

Several guidelines exist to assist industrial hygienists in interpreting the hazard posed by specific concentrations of gases and vapors in the workplace. The most commonly used in the United States are TLVs (Threshold Limit Values®), PELs (Permissible Exposure Limits), and RELS (Recommended Exposure Limits).

TLVs are established by a committee of the American Conference of Governmental Industrial Hygienists and composed of professionals working voluntarily. The ACGIH has published its TLVs for over 50 years. Threshold Limit Values (TLVs) refer to "airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects." (ACGIH, 2001). For some gases and vapors, short-term exposure limits (STELs) have also been established when exposure to higher concentrations for 15 minutes may lead to serious health consequences. See Appendix B for a listing of the TLVs and STELs. The ACGIH cautions that "these values are *not* fine lines between safe and dangerous concentrations"; they should be used as guidelines in evaluating exposures in particular workplace. Each year some of the TLVs are revised, and often new chemicals are added to the list. Although some countries have adopted the TLVs as legal limits, they were not intended for that purpose, and do not have the weight of law in the United States.

PELs, by contrast, are legal exposure limits in the United States and are established by the Occupational Safety and Health Administration (OSHA). OSHA initially adopted the 1968 TLVs® as PELs, and has since issued revised PELs for only 27 substances. The revised PELs include much more recent data, details on health effects, and often include more details on required monitoring and protections, including biological monitoring in some cases.

The National Institute for Occupational Safety and Health studies compounds of concern and issues Recommended Exposure Limits (RELs), along with reports on the scientific data upon which RELs are based, the *Criteria* documents. RELs may be used by OSHA in setting new PELs. In the meantime, RELs provide important guidance to the practicing industrial hygienist.

Each of these occupational exposure limits has its limitations. TLVs have been criticized because some feel that industry has had too much influence in their establishment, and the levels appear to be insufficiently protective given the scientific data presented; ACGIH has taken several steps to try to alleviate these concerns.The rulemaking procedure for PELs is arduous and subject to multiple hearings, comment periods, and legal appeals; this lengthy process has restricted the ability of OSHA to revise PELs as new health data have arisen in the past three decades. Thus, while TLVs have been established for more than 720 chemicals, PELs exist for only 412 chemicals. OSHA does state that the employer has a general duty to provide a safe workplace, and interprets this to imply that TLVs should be also be considered. Therefore, the industrial hygienist is best advised to make use of all available occupational exposure limits, PELs, TLVs, and RELs, and to understand the basis upon which such recommendations are made.

SOLVENTS

Organic Chemistry

Organic chemistry is the chemistry of the compounds of carbon. The carbon atom can form single, double, and triple covalent bonds to other carbon atoms and to atoms of other elements. A *molecular chain* (or *skeleton*) consists of a line of carbon atoms that can have branches of carbon atoms, or functional groups. These functional groups can contain oxygen (O), nitrogen (N), phosphorus (P), and sulfur (S), among others. A *functional group* in an organic molecule is a region where reactions can take place. Double and triple bonds and the presence of atoms other than carbon make up typical functional groups.

Organic compounds are named according to the number of carbon atoms in the basic skeletal chain. The location of the functional groups is designated by the number of the carbon atom to which it is attached. The common organic solvents can be classified as aliphatic, cyclic, aromatic, halogenated hydrocarbons, ketones, esters, alcohols, and ethers. Each class has a characteristic molecular structure, as shown in Table 7–A.

Compounds with only carbon and hydrogen atoms are called *hydrocarbons*. *Hydrocarbons* with all single bonds are alkanes, and are also known as saturated hydrocarbons, as they contain the maximum number of hydrogen atoms. Hydrocarbons forming chains are known as aliphatic or paraffin hydrocarbons, while those forming rings are identified with the prefix *cyclic-* or *cyclo-*. One very important cyclic hydrocarbon is benzene, which contains six carbon atoms and is very stable; compounds which contain benzene are described as aromatic compounds.

Halogenated hydrocarbons have chlorine, fluoride, iodine, and/or bromine atoms attached to a hydrocarbon. Ketones, esters, alcohols, and ethers all have an oxygen atom attached to a carbon atom, and examples are given in Table 7-A.

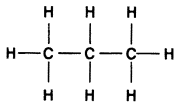
Isomers are molecules that have the same number and kinds of atoms, but the atoms are arranged differently, and thus have different physical and chemical properties. For example, both ethanol and dimethylether have two carbon atoms, six hydrogen atoms, and one oxygen atom, but the atoms are arranged differently, and the two compounds have quite different properties, e.g., dimethylether is a gas at room temperature, while ethanol is a liquid. A good working knowledge of the nomenclature, the characteristic molecular structure, and the different toxicities is helpful in making a proper assessment of an exposure.

Nomenclature itself can often be misleading. For example, trichloroethane and trichloroethylene are chlorinated hydrocarbons differing in the types of bonds and the arrangement of chlorine atoms. Trichloroethane is saturated whereas trichloroethylene has a carbon–carbon double bond. Trichloroethane is a saturated compound in which the three chlorine atoms may be attached to the same carbon atom (1,1,1-trichloroethane), or two may be attached to one carbon and one to the other carbon atom (1,1,2-trichloroethane); trichlorethylene has a double bond between the carbon atoms and there is only one possible arrangement of the chlorine atoms, two on one carbon and one on the other. These three compounds, 1,1,1-trichloroethane, 1,1,2-trichloroethane, and trichlorethylene, have very different toxicities and very different TLVs, 350 ppm, 10 ppm, and 50 ppm, respectively. On the other hand, 1,1,1 trichloroethane has been identified as an ozone-destroying chemical (see Air Pollution, later), and production was banned in the United States after Jan. 1, 1996. This example illustrates the importance of correctly identifying the chemical being used. These chemicals are easily confused due to slight difference in names, which might not be apparent to a worker with inadequate training.

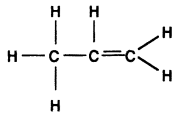
Common names may not impart any information as to the structure of a molecule (muriatic acid as compared to hydrochloric acid) and can even be misleading (ethylene dichloride is actually the completely saturated 1,2-dichloroethane); systematic names, using the International Union of Pure and Applied Chemistry rules, unambiguously describe the structure of a molecule. The *CRC Handbook of Chemistry and Physics* describes this system in detail.

Table 7–A. ***Major Classes of Organic Compounds***

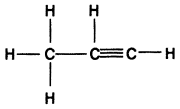
Aliphatic Hydrocarbons



alkane, C_nH_{2n+2}
propane



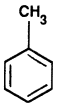
alkene, C_nH_{2n}
propene



alkyne, CnH_{2n-2}
propyne (methyl acetylene)

Aromatic Hydrocarbons

benzene, C_6H_6

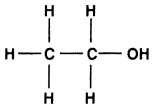


toluene, $C_6H_5CH_3$
(methyl benzene)

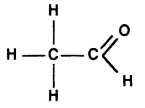
Cyclic Aliphatic Hydrocarbons

cyclohexane

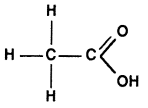
Oxygen-containing Functional Groups



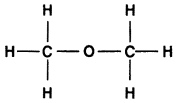
alcohol, ROH
ethanol



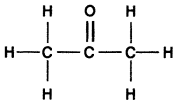
aldehyde, RCOH
ethanal (acetaldehyde)



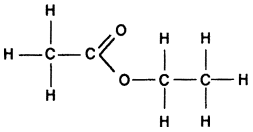
acid, RCOOH
ethanoic acid (acetic acid)



ether, ROR′
dimethy ether

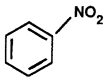


ketone, R(C = O)R′
dimethyl ketone (acetone)

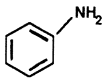


ester, RCOOR′
ethyl acetate

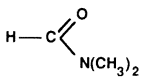
Nitrogen-containing Functional Groups



nitro-compound, RNO_2
nitrobenzene

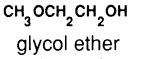


amine, RNH_2
aniline

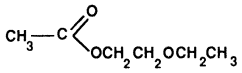


amide, RCONR′R″
dimethyl formamide (DMF)

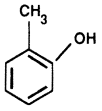
Miscellaneous Functional Groups



glycol ether
2-methoxyethanol

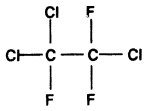


glycol ether ester
2-ethoxyethyl acetate
ethyl cellosolve



phenol, ROH
o-cresol

Halogenated Hydrocarbons



1,1,2-trichloro-1,2,2-trifluoroethane
(Freon TF)

Even a scientifically trained user often has only a vague and sometimes completely erroneous knowledge of the chemical preparation in use. It is a good practice to verify the specific name and composition of the solvents involved with direct evidence from the label, from the manufacturer's Material Safety Data Sheet, or from the laboratory. Only after verification of name and composition should one attempt to evaluate the potential effect or hazard of a solvent.

Manufacturers now are required by government regulations to provide information on the composition of their trade name materials. The minimum information is that contained in the Material Safety Data Sheet (MSDS) (Figure 7–1). Manufacturers can withhold proprietary information from an MSDS for general use, but are required to furnish it in cases of medical necessity.

Hawley's Condensed Chemical Dictionary, Windholz's *The Merck Index,* Gleason's *Clinical Toxicology of Commercial Products,* and the NFPA *Fire Hazard Properties of Flammable Liquids, Gases, and Vapors* provide general information and descriptions of many solvents, including trade name materials. These are helpful references for classifying and understanding the composition of a solvent.

HAZARDS OF GASES, LIQUIDS, SOLVENTS, AND VAPORS

Compressed Gas

The use of compressed gas cylinders has inherent dangers in their handling. If the tank were to fall and the valve snap off, the cylinder can become a projectile; therefore, one should always cap the valve before transporting cylinders of compressed gas, and the cylinders should be securely stored with double chains to prevent falling. They should also be protected from heat, which may cause a liquid to volatilize or react, and so generate greater pressures inside than the cylinder was designed to withstand. Attention should be paid to the reactivity of the gases with the regulators and lines. For this reason, copper should be avoided in systems with acetylene or ammonia. Regulators should be dedicated to use with single gases, and mixed use with potentially reactive gases should be strictly avoided. Often flammable gas cylinders are reverse threaded to prevent mixing with oxygen inside the regulator.

Gases

Commercially, gases are available as compressed or liquefied gases. Certain gases, such as nitrogen, helium, and some others that are available as liquefied gases, are used as a source of high-purity gas from boil-off or as a cryogenic fluid at the gas's boiling point (77 K or –196 C for liquid nitrogen). Table 7–B gives common industrial gases, cylinder pressures, and physical state. All of these readily volatilize, although some organometallic compounds typically available as liquefied gases must be heated to give an adequate working pressure.

Cryogenic Liquids

Cryogenic liquids pose several safety concerns in addition to frostbite from extreme cold. Spills of cryogenics rapidly vaporize, producing a gas that is initially significantly more dense than air, resulting in potential oxygen deficiency hazards in pits, vaults, and enclosed spaces. Given sufficient time, the gas reaches thermal equilibrium with its surroundings and disperses throughout the available space. Liquid nitrogen, the most common cryogenic fluid, boils at a lower temperature than liquid oxygen, providing a location for oxygen to condense out of the atmosphere into dewars (double-walled flasks with a vacuum between the walls) with the nitrogen. This creates a potential explosion hazard if the oxygen comes in contact with an oxidizable material. Cryogen dewars and cryogenic systems must have proper pressure relief to prevent pressure buildup and possible rupture as the liquid vaporizes. Full containment of a liquefied gas is usually not possible; helium requires about 18,000 pounds per square inch (psi) and nitrogen requires 43,000 psi. Table 7–C lists common cryogenic liquids.

Flammability, Explosions, and Reactivity

Some gases are very pyrophoric. Silane is used extensively in the semiconductor industry, but is a well-recognized fire hazard as it will ignite spontaneously when exposed to air; silane has been responsible for several serious fires causing millions of dollars of damage. Perchloric acid is a strong oxidizing agent which can cause fire and explosions. Some solvents, e.g., some ethers, are unstable over time, and degrade into explosive compounds.

Depending on their flash points, liquids may be flammable or combustible, as described by the National Fire Protection Association (see NFPA 30, *Flammable and Combustible Liquids Code* and NFPA 325, *Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids*).

FLASH POINTS

The flash point of a liquid is the lowest temperature at which it gives off enough vapor to form an ignitable mixture with the air near the surface of the liquid or in a vessel capable of flame propagation away from the source of ignition. Some evaporation takes place below the flash point, but not in sufficient quantities to cause an ignitable mixture. Flash points can be determined by using either closed-cup or open-cup testers. Open-cup flash points are determined with the liquid in the open air and are generally 10 to 20 percent higher than closed-cup flash point figures for the same substance. When open-cup flash point figures are given, they are usually identified by the initials *OC*.

FLAMMABLE LIQUIDS

A liquid with a closed-cup flash point below 100 F (37.8 C) and a vapor pressure not exceeding 40 psi absolute (psia) at 37.8 C is a Class I liquid. Class I liquids are subdivided as follows:

- Class IA liquids include those with a flash point below 73 F (22.8 C) and a boiling point below 100 F (37.8 C).

Material Safety Data Sheet
May be used to comply with
OSHA's Hazard Communication Standard,
29 CFR 1910.1200. Standard must be
consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*	*Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.*

Section I

Manufacturer's Name	Emergency Telephone Number
Address *(Number, Street, City, State, and ZIP Code)*	Telephone Number for Information
	Date Prepared
	Signature of Preparer *(optional)*

Section II — Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% *(optional)*

Section III — Physical/Chemical Characteristics

Boiling Point		Specific Gravity (H_2O = 1)	
Vapor Pressure (mm Hg.)		Melting Point	
Vapor Density (AIR = 1)		Evaporation Rate (Butyl Acetate = 1)	

Solubility in Water

Appearance and Odor

Section IV — Fire and Explosion Hazard Data

Flash Point (Method Used)	Flammable Limits	LEL	UEL

Extinguishing Media

Special Fire Fighting Procedures

Unusual Fire and Explosion Hazards

(Reproduce locally) OSHA 174, Sept. 1985

Figure 7–1. Material Safety Data Sheet. This form or an equivalent is used by manufacturers and distributors to provide health and safety information on solvents. (Continues)

Section V — Reactivity Data

Stability	Unstable		Conditions to Avoid
	Stable		

Incompatibility (*Materials to Avoid*)

Hazardous Decomposition or Byproducts

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur		

Section VI — Health Hazard Data

Route(s) of Entry: Inhalation? Skin? Ingestion?

Health Hazards (*Acute and Chronic*)

Carcinogenicity: NTP? IARC Monographs? OSHA Regulated?

Signs and Symptoms of Exposure

Medical Conditions
Generally Aggravated by Exposure

Emergency and First Aid Procedures

Section VII — Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled

Waste Disposal Method

Precautions to Be Taken in Handling and Storing

Other Precautions

Section VIII — Control Measures

Respiratory Protection (*Specify Type*)

Ventilation	Local Exhaust	Special
	Mechanical (*General*)	Other

Protective Gloves	Eye Protection

Other Protective Clothing or Equipment

Work/Hygienic Practices

Page 2

☆ U.S.G.P.O. 1986-491-529/45775

Figure 7–1. (Concluded)

Table 7–B. *Selected Compressed and Liquefied Gases*

Gas	Formula	Form	*Cylinder Pressure (psig)*
Ammonia	NH_3	Liquid	114
Argon	Ar	Gas	225–6,000
Arsine	AsH_3	Liquid	190–205
Carbon dioxide	CO_2	Liquid	830
Helium	He	Gas	225–6,000
Hydrogen	H_2	Gas	225–3,500
Hydrogen chloride	HCl	Liquid	613
Hydrogen fluoride	HF	Liquid	0.6
Methane	CH_4	Gas	1,500–2,300
Neon	Ne	Gas	225–1,900
Nitrogen	N_2	Gas	225–6,000
Nitrous oxide	N_2O	Liquid	745
Oxygen	O_2	Gas	225–2,200
Phosphine	PH_3	Liquid	400–590
Silane	SiH_4	Gas	150–1,200

Reprinted with permission from Matheson Gas Products, *Matheson Gases & Equipment,* 1993.)

- ➢ Class IB liquids include those with a flash point below 73 F (22.8 C) and a boiling point at or above 100 F (37.8 C).
- ➢ Class IC liquids include those with a flash point at or above 73 F (22.8 C) and below 100 F (37.8 C).

COMBUSTIBLE LIQUIDS

Liquids with a closed-cup flash point at or above 100 F (37.8 C) are called combustible liquids, which are subdivided as follows:

- ➢ Class II liquids include those with a flash point at or above 100 F (37.8 C) and below 140 F (60 C).
- ➢ Class IIIA liquids include those with a flash point at or above 140 F (60 C) and below 200 F (93.4 C).
- ➢ Class IIIB liquids include those with a flash point at or above 200 F (93.4 C).

FIRE POINT

The fire point of a liquid is the lowest temperature at which vapors evolve fast enough to support continuous combustion. The fire point temperature is usually about 5 F above the flash point temperature.

FLAMMABLE RANGE

A prominent factor in rating the fire hazard of a flammable liquid or gas is its flammable range, sometimes called the explosive range. For each flammable liquid or gas, there is a minimum concentration of its vapor, in air, below which propagation of flame does not occur on contact with a source of ignition because the mixture is too lean. Propagation of flame is the self-sustaining spread of flame through the body of the flammable vapor-air mixture after introduction of the source of ignition; a vapor-air mixture at or below its lower explosive limit can burn at the point of ignition without propagating. There is also a maximum concentration of vapor, in air, above which propagation of flame does not occur because the mixture is too rich. The mixtures of vapor with air that, if ignited, just propagate flame are known as the lower and upper flammable (or explosive) limits, and are usually expressed in terms of percentage by volume of vapor in air.

Table 7–C. *Common Cryogenic Liquids*

Cryogen	Boiling Point (C)
Argon	–186
Helium	–287
Hydrogen	–252
Neon	–245
Nitrogen	–196
Oxygen	–183

(Reprinted with permission from Lide DR, Frederickse HPR, eds. *CRC Handbook of Chemistry and Physics,* 75th ed. Boca Raton, FL: CRC Press, 1994.)

The flammable (or explosive) range includes all the concentrations of a vapor in air between the lower explosive limit (LEL) or lower flammable limit (LFL) and the upper explosive limit (UEL) or upper flammable limit (UFL). The lower flammable limit is important because if this percentage is small, it takes only a small amount of the liquid vaporized in air to form an ignitable mixture.

It also should be noted that if the concentration of vapor in the vapor-air mixture is above the upper flammable limit, introduction of air (by ventilation or other means) produces a mixture within the flammable range before a safe concentration of vapor below the lower flammable limit can be reached.

For a large number of common liquids or gases, the LEL is a few percent and the UEL is 6-12 percent, although there are notable exceptions. The LEL and UEL for hydrogen are 4 and 75 percent and for anhydrous hydrazine they are 4.7 and 100 percent, respectively. For specific materials, consult the material safety data sheet or NFPA 325. For hazardous vapors, if the airborne concentration is kept below the PEL or TLV, the concentration is less than the LEL (note that a concentration of 1 percent by volume is 10,000 ppm).

REQUIREMENTS AND GUIDELINES

The occupational safety requirements for the handling and use of flammable and combustible liquids and gases are given in Subpart H of 29 *CFR* 1910. These rules are based on the 1965–1970 editions of the NFPA guidelines current at the time the OSHA standards were first written. Best management practice suggests that current NFPA guidelines should be followed to the extent feasible. Compliance with Subpart H is a minimum.

TOXICOLOGICAL EFFECTS

Site of Action

For some toxicants, the site of action is at the point of exposure, i.e., the skin or the respiratory tract. For others, the target organ is more distant, or the effect is systemic.

Water-soluble gases are more likely to be upper respiratory tract irritants (e.g., HF, ammonia, sulfuric acid), while the less soluble gases (nitrogen dioxide, ozone, phosgene) pass through the upper airways and penetrate to the bronchioles and alveoli where they may have a delayed reaction and cause acute pneumonitis and pulmonary edema hours later. Chemicals which might otherwise deposit in the upper respiratory tract may penetrate into the deep lung if they are adsorbed to particles.

Asphyxiation

Oxygen is essential to life, and delivery of oxygen to the cells is equally vital. Gases and vapors can interfere with the supply of oxygen in two fundamental ways: simple asphyxiants exert no direct action, but act passively by merely replacing oxygen in the air so that the concentration of oxygen falls below the 18 percent minimum required for life. Any gas or vapor, even nitrogen, can act as a simple asphyxiant if its concentration is high enough. By contrast, chemical asphyxiants react with essential cellular molecules to disrupt the transport or use of oxygen. Carbon monoxide forms a very stable complex with hemoglobin, and so blocks the readily reversible interaction of hemoglobin with oxygen that is crucial to carrying oxygen to the cells. Chemical asphyxiants may also interfere with the cell's ability to use the oxygen which is delivered, e.g., cyanide and hydrogen sulfide inhibit cytochrome oxidase enzymes and so disrupt the normal reactions of the cell.

Organic and Inorganic gases

Simple gases (low-molecular-weight hydrocarbons such as methane, ethane, and propane), nitrogen, hydrogen, the inert gases (helium, neon, and argon), and some compounds (CO_2) have no significant toxicity of their own. They are simple asphyxiants; they dilute oxygen in the atmosphere. These elements and compounds have either no or very minimal odor and thus have poor warning properties.

The oxides of carbon, nitrogen, and sulfur can be produced by use of oxygen acids, combustion, welding, chemical cleaning or electroplating, or a variety of other processes. Decomposition of organic material may produce toxic (hydrogen sulfide) or flammable (methane) atmospheres. Others, such as ammonia, boron halides, phosphine, arsine, and silane, are used as reactants in industrial and manufacturing processes. Others, such as the reactive, volatile metal halides, are used in research.

In all of these cases, reactivity of the gas is important. The oxides may react with moisture in the mucous membranes to form acids; ammonia, an alkaline gas, acts as a primary irritant. Boron or volatile metal halides react spontaneously in moist air to form gaseous hydrogen halides. Phosphine and silane are spontaneously flammable in air. Arsine and phosphine are also highly toxic.

Exposure control relies primarily on engineering controls. Dilution ventilation *may* be sufficient for the simple asphyxiants. Local exhaust ventilation is suitable for many processes. The more reactive or highly toxic compounds require complete control (exhaust ventilation, gas sensors, all-welded construction for gas lines, excess flow-controllers, automatic shut-down systems, etc.) to ensure protection of the workers.

Inorganic Acids and Bases

Strong acids and bases are corrosive and can burn the skin and mucous membranes. Health effects are variable and concentration-dependent, most often on the site of contact with tissue; they include irritation of mucous membranes or respiratory tract by HCl, chemical burns by the concentrated solutions, oxidation by HNO_3 (an oxidizing acid), and dehydration by H_2SO_4. The highly toxic acids H_2S and HCN act differently from other acids; they complex with metal-containing enzymes (cytochromes), preventing cellular oxygen metabolism.

Concentrated HF is particularly corrosive to tissue and bone. Pain from HF solutions stronger than 50 percent is felt within a few minutes; lower concentrations may not produce pain for several hours. Serious tissue damage may result without the person being aware of it. HF burns require immediate action: Irrigate the exposed area to flush away as much HF as possible and seek medical attention immediately. Treatment is dependent on the severity of the burn; mild cases can be managed with magnesium oxide but more severe burns may require infiltration of the affected tissue with calcium gluconate.

Engineering controls and protective equipment should be used to limit exposure. Use of personal protective equipment is essential for working with concentrated acids. Chemical compatibility of the protective clothing with the acid must be considered to ensure protection of the worker (see Johnson, Swope, Goydan, et al, 1991).

Other Aqueous Solutions and Systems

These are known for their irritant effects after prolonged exposure. Contact dermatitis from aqueous solutions is quite common, usually appearing as "dishpan hands." Excessive levels of mists in the air (resulting from heating, agitation, and spraying) can cause throat irritation and bronchitis. Many other effects and hazards are possible if chemicals react with their containers. Bretherick (1990) and Lewis (1997) cite a number of examples. As a rule, aqueous systems, because of their low vapor pressure and ease of control, are a lesser problem, but they cannot be dismissed as potential hazards.

Solvents and Solvent Vapors

Organic solvents can have an array of toxic effects on humans; some effects are similar for all solvents, and other effects are specific to particular solvents or their metabolites. While the common effects generally occur at relatively high concentrations of solvent vapors, the specific effects tend to become manifest at lower concentrations.

Direct contact of solvents with the skin can cause irritation, defatting of the skin, and dermatitis. Some solvents, especially less polar (lipophilic) solvents, can penetrate the skin, so dermal exposure to solvents can be an additional route of exposure. Some recent experiments have demonstrated that solvent vapors can also be absorbed through the skin.

At very high concentrations (thousands of ppm), solvent vapors may cause simple asphyxiation by displacing oxygen. This is most likely to occur in confined spaces. At high concentrations (typically hundreds of ppm) solvents tend to have a rapid effect on the central nervous system which results in dizziness, disorientation, confusion, euphoria, and giddiness; prolonged exposure at high levels can lead to loss of consciousness, paralysis, convulsion, and, ultimately, death from respiratory or cardiac arrest.

In addition to these effects of solvents in general, specific solvents may have specific toxicities. Organ systems that are affected by some solvents include the liver, the kidney, the central nervous system, and the peripheral nervous system.

PHYSIOLOGICAL EFFECTS

Some of the effects are outlined in the following paragraphs. For detailed information on specific organic solvents, consult Clayton and Clayton's *Patty's Industrial Hygiene and Toxicology,* Gerarde's *Toxicology and Biochemistry of Aromatic Hydrocarbons,* The American Conference of Governmental Industrial Hygienists *Documentation for the Threshold Limit Values,* the American Industrial Hygiene Association (AIHA) *Hygienic Guide Series,* and the NIOSH *Registry of Toxic Effects of Chemical Substances* or the NIOSH criteria document on the subject solvent (see Bibliography).

Hydrocarbons

ALIPHATIC HYDROCARBONS

The aliphatic compounds take their name from the Greek word *aliphe,* meaning fat, because fats are derivatives of this class of hydrocarbons (see Table 7–A).

Aliphatic hydrocarbons are further classified as alkanes, alkenes, cycloalkanes, cycloalkenes, alkynes (acetylenes), and arenes (an aliphatic group is bonded to an aromatic ring). Petroleum and natural gas are the most important sources of alkanes, alkenes, and cycloalkanes. Coal tar is an important source of arenes. High-molecular-weight alkanes are broken down (cracked) catalytically to increase the yield of gasoline from petroleum. Ethylene (H_2CCH_2) is an important by-product of cracking and is used to make plastics and ethanol (CH_3CH_2OH).

The saturated aliphatic hydrocarbons, C_nH_{2n+2}, known as alkanes, are those with all bond positions saturated by bonding with hydrogen. Compounds in this series have the characteristic *-ane* suffix, as in isobutane, 2-methylpentane, and 2, 2-dimethylpentane. They are as inert biochemically as they are chemically. Even as air pollutants, they are among the least reactive and do not pose a significant problem. The alkanes are good solvents for natural rubber. They act primarily as CNS depressants.

A relatively high level is required for toxic effects. The TLVs generally range from 100 ppm and higher. The exception is n-hexane (or normal hexane, the straight-chained isomer), with a TLV of 50 ppm. Repeated exposures to excessive concentrations may cause peripheral neuropathy, although other isomers have not been found to have this health effect.

The unsaturated aliphatic hydrocarbons, the alkenes (C_nH_{2n}) and the alkynes (C_nH_{2n-2}), with double and triple bonds respectively, are similarly inert in the body. However, they are more chemically reactive than the saturated hydrocarbons. As air pollutants, they are reactive and create a control problem. The primary health problem associated with the aliphatics is dermatitis.

Crude oil (petroleum) is mainly a very complex mixture of aliphatic compounds. It contains alkanes, alkenes, cycloalkenes, and arenes, as well as small amounts of nitrogen and sulfur compounds, which vary depending on the source.

Petroleum is separated into mixtures of hydrocarbons by fractional distillation. Gasoline is the fraction of petroleum boiling between room temperature and 200 C and is mainly made up of C_5 to C_{11} hydrocarbons, with C_8 predominating. It has been estimated that there are as many as 500 different hydrocarbons in gasoline alone. About 150 of them have been separated and identified.

CYCLIC HYDROCARBONS

The cyclic hydrocarbons act much in the same manner as the aliphatics, but they are not quite as inert. A significant percentage of cyclic hydrocarbons are metabolized to compounds with a low level of toxicity.

The lower molecular weight cycloalkanes (cyclopropane and cyclobutane) have been used as anesthetics. The cycloalkanes typically are CNS depressants, but as molecular weight increases, the margin of safety between anesthesia and adverse health effects decreases. The unsaturated cyclic hydrocarbons generally are more irritating than the saturated forms. This may be due in part to the reactivity of the carbon–carbon double bond. For example, cyclopentane causes slight reddening and drying of the skin and cyclopentene causes moderate to severe irritation of the skin and eyes.

AROMATIC HYDROCARBONS

These get their names from *aroma,* meaning pleasant odor. The molecules are usually characterized by one or more six-carbon rings (benzene) or fused rings (naphthalene or larger rings). This classification once served to distinguish petroleum and coal-tar hydrocarbon solvents. Now, however, aromatics are derived from both sources.

Benzene and other aromatics do not undergo the addition reactions shown by alkenes and alkynes, but do undergo aromatic substitution reactions in which an atom or group of atoms replaces one of the hydrogen atoms on the ring. Aromatic substitution reactions of benzene produce a wide variety of useful products (see Table 7–A). The aromatic hydrocarbon benzene is notorious for its effect on the blood-forming tissues of the bone marrow and as a cause of aplastic anemia. Gerarde (see Bibliography) has shown that, in animals, injury may result from a single exposure. Benzene is now indicated as a leukemogenic agent. This has greatly reduced the extent of its use as a solvent. Toxic levels of benzene are easily absorbed through the skin and inhaled. Benzene should not be used for cleaning processes or for any process requiring skin contact or where the concentration in the air is not controlled by proper ventilation. The 2001 TLV® for benzene is 0.5 ppm, with an A1 (confirmed human carcinogen) classification. However, NIOSH recommended that the PEL be reduced to 0.1 ppm, averaged over an 8-hour period, and that benzene be regulated as an occupational carcinogen.

The aromatic hydrocarbons in general are local irritants and vasodilators that cause severe pulmonary and vascular injury when absorbed in sufficient concentrations. They also are potent narcotics. The primary problems with common aromatic solvents other than benzene are dermatitis and effects on the central nervous system (CNS). Benzene can also be a contaminant of industrial toluene and xylene.

HALOGENATED HYDROCARBONS

The halogens are a group of five elements: fluorine, chlorine, bromine, iodine, and astatine. The halogens are a remarkable family of elements, marked by their great chemical activity and unique properties. Stability, nonflammability, and a wide range of solvency are but a few of the characteristics imparted by their application (see Table 7–A). Halogenated hydrocarbons are organic compounds in which one or more hydrogens have been replaced by fluorine, chlorine, or bromine, or rarely, iodine. The effects of the halogenated hydrocarbons vary considerably with the number and type of halogen atoms present in the molecule. Carbon tetrachloride at one end of the scale is highly toxic, causing acute injury to the kidneys, liver, CNS, and gastrointestinal tract. The 2000 TLV® for carbon tetrachloride is 5 ppm (A2 classification—suspected human carcinogen); however, NIOSH recommends that the PEL be reduced to a short-term exposure limit (STEL) of 2 ppm averaged over a 1-hour period and that the chemical be regulated as an occupational carcinogen.

Chronic exposure to carbon tetrachloride also damages the liver and kidneys and is suspected of causing liver cancer. Carbon tetrachloride has become the classic liver toxicant for use in studies on the effects of damage to the liver. As with benzene, this solvent should not be used for open cleaning processes where there is skin contact or where the concentration in the breathing zone may exceed recommended levels. Its use should be avoided altogether.

Replacing some of the chlorine atoms with fluorine as in 1,1,2-trichloro-1,2,2-trifluoroethane (Freon TF) produces a compound with a low level of toxicity. Its present eight-hour TLV is 1,000 ppm with 1,250 ppm as a ceiling limit. The depressant effect on the CNS and cardiac arrhythmias occur at concentrations much greater than the TLV. Because it is nonflammable and of low toxicity, it may be a suitable substitute for the more hazardous chlorinated solvents; however, environmental considerations such as ozone depletion preclude its application in many cases.

The chlorinated hydrocarbons, in general, are more toxic than the common fluorinated hydrocarbon solvents, although there are significant exceptions such as perfluoroisobutylene (TLV = 0.01 ppm, ceiling). Specific effects and toxicities vary widely, but the most common effects from the chlorinated hydrocarbons of intermediate toxicity (trichloroethylene, for example) are CNS depression, dermatitis, and injury to the liver. There is disagreement as to the carcinogenicity of 1,1,1-trichloroethane; the ACGIH TLV® carcinogen classification is A4, not suspected as a human carcinogen, but other organizations, such as NIOSH, consider 1,1,1-trichloroethane to be a carcinogen.

In addition, the chlorinated hydrocarbons, especially trichloroethylene, are noted for their synergistic effects with alcohol consumption. These include flushed, red face and personality changes. These effects must be taken into account when evaluating industrial exposure.

Perchloroethylene (tetrachloroethylene), commonly used in dry cleaning, textile processing, and other industrial processes, has been suggested as a potential human carcinogen. Recent animal lifetime exposure studies (National Toxicology Program, 1986) did show an increased tumor incidence. Earlier animal data, in some cases, are confounded by simultaneous exposure to epichlorohydrin (a known mutagen); human epidemiology is confounded by concomitant exposures to other chlorinated solvents, smoking, and other factors. In its *Seventh Annual Report on Carcinogens, 1994* the National Toxicology Program stated that there is sufficient evidence for the carcinogenicity of perchloroethylene in experimental animals and cited an International Agency for Research on Cancer (IARC) working group conclusion that there are insufficient data to evaluate its carcinogenicity in humans (National Toxicology Program, 1994).

Refrigerants (Freon, chlorofluorocarbons or CFCs, and hydrochlorofluorocarbons or HCFCs) are a subclass of the halogenated hydrocarbons. The majority of these are methane or ethane derivatives, with a few higher carbon analogues and

some other inorganic and organic gaseous compounds. The materials in current use are generally of low toxicity and exposure limits and guidelines tend to be high; the TLV for trichlorofluoromethane (R-11) is a ceiling of 1,000 ppm. The TLV for chlorodifluoromethane (R-22) is 1,000 ppm. New refrigerants have come on the market as a result of the EPA incentives to produce nonozone-depleting refrigerants. There are no exposure standards or guidelines for these compounds other than those suggested by the manufacturer. Safety of some of the new refrigerants has come under question as benign tumors have been seen in long-term animal studies. Refrigerant safety has been reviewed by Calm (1994) and engineering controls have been addressed by ASHRAE (see Bibliography).

NITROHYDROCARBONS

These vary in their toxicological effects, depending on whether the hydrocarbon is an alkane or an aromatic hydrocarbon. Nitroalkanes are known more for their irritant effects accompanied by nausea; effects on the CNS and liver become significant during acute exposures. 2-Nitropropane is listed as a confirmed animal carcinogen, but with an assigned TLV of 10 ppm. The nitroaromatics (such as nitrobenzene with a TLV of 1 ppm) are much more acutely hazardous. They cause the formation of methemoglobin and act on the CNS, the liver, and other organs.

Oxygen-Containing Functional Groups

These are found in the alcohols, aldehydes, ketones, carboxylic acids and their esters, anhydrides, and the ethers.

ALCOHOLS

One of the most important classes of industrial solvents is characterized by the presence of a hydroxyl group (-OH). Saturated alcohols are widely used as solvents. All alcohols are formed by the replacement of one or more hydrogen atoms by one or more hydroxyl groups.

These polar compounds are classified on the basis of both the number of hydroxyl groups and the nature of the radicals attached to the hydroxyl groups. The monohydric alcohols, which contain one hydroxyl group, are known simply as alcohols; dihydric alcohols have two hydroxyl groups and are known as glycols; trihydric alcohols have three hydroxyl groups and are called glycerols or polyols.

The alcohols are noted for their effect on the CNS and the liver but they vary widely in their degree of toxicity.

Methanol (CH_3OH) and ethanol (CH_3CH_2OH) are the two most important industrial alcohols. Methanol is made by catalytic hydrogenation of carbon monoxide and may one day replace gasoline and natural gas as a fuel because it can be made from coal. Ethanol is made by fermentation of starch (or other carbohydrates) and by hydration of ethene.

Methanol causes several types of injuries, notably impairment of vision and injury of the optic nerve. Methanol slowly produces toxic metabolites. For this reason, its chronic toxicity is greater than that of ethanol.

Ethanol is used industrially in a denatured form. It is quickly metabolized in the body and largely converted to carbon dioxide, and is the least toxic of the alcohols. Any toxicity it causes can be more related to the denaturants (such as benzene or methanol). The undesirable effects of ethanol primarily are related to its recreational use, which affects the drinker's physical safety and can compound the effects of other solvents or medications.

Alcohol is a depressant, not a stimulant. Medically, alcohol depresses the CNS, slowing down the activity of the brain and spinal cord. A large enough dose of alcohol can sedate the brain to a point where involuntary functions such as breathing are lost, causing death.

Propanol is metabolized to toxic by-products and is more toxic than ethanol when taken internally but less toxic than the higher homologues.

ALDEHYDES

These are well-known causes of skin and mucosal irritation and CNS effects. Dermatitis from the aldehydes is common. The aldehydes also are characterized by their sensitizing properties. Allergic responses are common.

KETONES

These have become increasingly important solvents for acetate rayon and vinyl resin coatings. Ketones are stable solvents with high dilution ratios for hydrocarbon diluents. They are freely miscible with most lacquer solvents (low-molecular-weight alcohols, aromatics, and esters) and diluents, and their compatibility with lacquer ingredients gives an acceptable finish to many products. Generally, ketones are good solvents for cellulose esters and ethers and many natural and synthetic resins.

The common ketones (such as acetone or methyl ethyl ketone, MEK) generally exert a narcotic-type action. All are irritating to the eyes, nose, and throat, so high concentrations are not usually tolerated. Methyl ethyl ketone in conjunction with toluene or xylene has been reported to cause vertigo and nausea. Lower tolerable concentrations may impair judgment and thereby create secondary hazards. The lower saturated aliphatic ketones are rapidly excreted and for this reason cause only minor systemic effects. Methyl n-butyl ketone received widespread attention during the 1970s, when it was pinpointed as the etiological agent producing a high incidence of peripheral neuropathy in one working population.

ESTERS

These are produced by the reaction of an organic acid with an alcohol. The particular properties of the esters are, therefore, partly determined by the parent alcohol. Esters often have pleasant odors. Esters in low concentrations are used as artificial fruit essences, flavorings, or components of perfumes. The esters are good solvents for surface coatings. Esters in high concentrations are noted for their irritating

effects to exposed skin surfaces and to the respiratory tract. They also are potent anesthetics. Cumulative effects of the common esters used as solvents are not significant except for conditions resulting from irritation. Esters of some mineral acids, such as dimethyl sulfate, are highly toxic.

ETHERS

These are made up of two hydrocarbon groups held together by an oxygen atom. They are made by combining two molecules of the corresponding alcohol. Compared with alcohols, ethers are characterized by their greater volatility, lower solubility in water, and higher solvent power for oils, fats, and greases. Because of their nonreactivity with solutes and ease of recovery, ethers are widely used for extraction. Mixtures of the lower alkyl ethers with alcohols make efficient solvents for cellulose esters. The epoxides (cyclic ethers) differ from other ethers, which are chemically inert, because their unstable three-membered rings make them highly active chemically. Because the epoxides react with the unstable hydrogen atom from water, alcohols, amines, and similar substances, they form a wide range of industrially important compounds.

The primary reactions to the saturated and unsaturated alkyl ethers, such as ethyl and divinyl ether, are anesthesia and irritation of the mucous membranes. However, the greatest safety hazard of these ethers is their tendency to form explosive peroxides. Once opened, ethers should be used within a short period of time, stored so that peroxides are destroyed as they are formed, or checked for the presence of peroxides. The ethers vary in their rate of peroxide formation; diisopropyl ether is one of the most rapid. Halogenated ethers (such as bis-chloromethyl ether) generally are highly toxic and the reader should refer to the more comprehensive references for information on these materials (see Bibliography, especially Clayton and Clayton, the AIHA *Hygienic Guide Series,* and the OSHA standards).

GLYCOLS, GLYCOL ETHERS, AND THEIR ESTERS

The glycols, like the cellosolves and the carbitols, are colorless liquids of mild odor. They are miscible with most liquids (organic and aqueous) and owe this wide solubility to the presence of the hydroxyl, the ether, and alkyl groups in the molecule. The glycol dialkyl ethers are pure ethers with a mild and pleasant odor. They are better solvents for resins and oils than are the monoethers. As a rule, these compounds are more volatile than the monoethers with the same boiling point.

The glycol ethers exert their effects on the brain, the blood, the reproductive system, and the kidneys. Of these, 2-methoxyethanol (ethylene glycol monomethyl ether), 2-ethoxyethanol (ethylene glycol monoethyl ether), and their acetates are the most toxic. They are rapidly absorbed through the skin and elicit neurological symptoms, including changes in personality. They also affect the reproductive system in both men and women. The higher-molecular-weight glycol ethers (such as propylene glycol and ethylene glycol monobutyl ether), on the other hand, are much less toxic. Work with 2-methoxyethanol, 2- ethoxyethanol, or their acetates should be conducted so as to preclude any skin contact. OSHA is proposing to reduce the PELs for 2-methoxyethanol and its acetate from 25 ppm to 0.1 ppm and for 2-ethoxyethanol and its acetate from 200 and 100 ppm, respectively, to 0.5 ppm.

Recent epidemiological studies in the semiconductor industry have associated spontaneous abortion (Swan et al, 1995; Correa et al, 1996) and reduced fecundability (Eskenazi et al, 1995) among fabrication workers who used 2-methoxyethanol, 2-ethoxyethanol, or their acetates, despite the fact that airborne concentrations were under 0.1 ppm (Hammond et al, 1996), that is, under the proposed OSHA standard.

OTHER FACTORS

Other factors must be taken into consideration. For example, handling procedures and type of clothing determine the degree of skin contact and so will affect dermal absorption. Even the degree of a user's respect for the hazard potential can be a decisive factor.

Ignition temperature, flash point, and other factors determining the potential for fire and explosion also must be considered. Although concentrations that are safe from a toxicological viewpoint are much lower than the lower flammable limits of flammable solvents, concentrations at potential points of ignition may be far higher than concentrations in the user's breathing zone.

Evaluation of hazard potential requires assessment of the consequences of exposure, the degree of exposure, and all factors contributing to the exposure.

AIR POLLUTION

In 1970 the Clean Air Act was passed by the U.S. Congress, and the U.S. Environmental Protection Agency began regulating criteria air pollutants. Four of the six criteria pollutants are gases: carbon monoxide, sulfur dioxide, ozone, and nitrogen oxides.

For the first 20 years, the U.S. EPA regulated only six criteria pollutants, the four gases, lead, and particulate matter. The 1990 Clean Air Act listed 189 hazardous air pollutants, most of which are vapors, and authorized the U.S. EPA to add additional hazardous air pollutants to its list. The concentrations of these are not regulated, but EPA will at some future time issue regulations to reduce emissions from sources, which will be required to use the Maximum Available Control Technology to reduce pollutant releases. Although the initial regulations will target major sources, small sources will be studied if further reductions are deemed necessary.

Solvents and other chemicals may become hazardous to the public in the form of air pollutants when released outdoors. Hydrocarbons are a major factor in the formation of photochemical smog. In the presence of sunlight, they react with atomic oxygen and ozone to produce aldehydes, acids,

oxides of nitrogen and sulfur, and a series of other irritant and noxious compounds.

The greatest portion of hydrocarbons contributing to air pollution originates from automobiles, but a significant amount also comes from the tons of solvents exhausted daily from industrial cleaning and surface-coating processes.

Nitric oxide (NO) is produced by the reaction of nitrogen with oxygen in high-temperature combustion, as in automobiles and fuel-burning power plants. Nitric oxide is photochemically oxidized to nitrogen dioxide (NO_2), a corrosive and an irritant. Nitrogen dioxide is an energy trap, reacting with sunlight to form nitric oxide and atomic oxygen:

$$NO_2 + h\upsilon \rightarrow NO + O$$

Atomic oxygen is highly reactive, forming ozone and initiating a host of secondary photochemical reactions. The nitric oxide produced can again react to produce more nitrogen dioxide, propagating the process. The yellow-brown haze seen over many cities is made up of nitrogen dioxide and its reaction products. Ozone in the troposphere (the atmosphere less than 10 km altitude) detracts from air quality and damages the lung.

Some compounds are more reactive to sunlight and contribute heavily to the smog problem. The use of such solvents is being curtailed in more and more areas, especially large cities. Other solvents are less reactive and are exempt from stringent control. Here, they are listed in decreasing order of photochemical reactivity as a general guide.

- Alkenes (unsaturated open-chain hydrocarbons containing one or more double bonds)
- Aromatics (except benzene)
- Branched ketones, including methyl isobutyl ketone
- Chlorinated ethylenes, including trichloroethylene (except perchloroethylene)
- Normal ketones (for example, methyl ethyl ketone)
- Alcohols and aldehydes
- Branched alkanes
- Cyclic alkanes
- Normal alkanes
- Benzene, acetone, perchloroethylene, and the saturated halogenated hydrocarbons

Opinion is divided as to the exact order of reactivity and many solvents have yet to be tested. The trend is toward the development and use of nonreactive solvent blends.

Upper Atmosphere Effects

In addition to the smog-related materials discussed previously, fluorocarbons such as trichlorotrifluoroethane and related materials catalyze the destruction of ozone in the upper atmosphere. Ozone in the stratosphere (the atmosphere 10–50 km in altitude) absorbs solar ultraviolet radiation at the 290-nanometer (nm) wave length. Should the destruction of ozone by fluorocarbons and other materials prove to be significant, the amount of solar ultraviolet radiation reaching the earth's surface will increase. This would impair agricultural production and increase the incidence of skin cancer. In 1987, the industrialized nations met and signed the Montreal Protocol on Substances that Deplete the Ozone Layer. The Montreal Protocol calls for the reduction of use and elimination of the major ozone-depleting chemicals.

Global Warming

Carbon dioxide, the product of combustion of carbon-based fuels, contributes to the greenhouse effect. Put simply, solar radiation penetrates the atmosphere and is absorbed by the earth; a portion is radiated back into space, and a portion is consumed in life processes and atmospheric chemical reactions, thus setting up a thermal equilibrium. Carbon dioxide absorbs the shorter wavelength energy re-radiated into space; this energy is then manifested as heat. It has been estimated that an increase of CO_2 concentration to 370 ppm from the present value of about 320 ppm would increase the temperature 0.5 C. In reality, other factors, such as cloud cover, atmospheric water vapor and particulates, and weather patterns all affect the process and may offset the warming trend of carbon dioxide.

EVALUATION OF HAZARDS

A prime question regarding any process using a volatile chemical is whether the concentration of the solvent in the air exceeds acceptable limits. Getting the answer to this is not as difficult as it may seem.

A knowledge of the chemical, its properties, and the process in which it is used should give the investigator some idea of the potential hazards.

If a chemical of high-hazard potential is being used, if the equipment and ventilation system are poorly designed, or if performance of the system is questioned, then there is a greater probability of physiological injury and immediate action should be taken to evaluate and reduce the hazard before it becomes a problem.

The evaluation procedure, where the industrial hygienist assesses the degree of risk in the workplace, is based on the following factors:

- The toxicity of the substance
- The concentration in the breathing zone
- The manner of use
- The length of time of the exposure
- The controls already in place and their effectiveness
- Any special susceptibilities on the part of the employees

Samples can be collected in the field and returned to the laboratory for analysis or (and this is the trend) they may be collected and analyzed on the spot with direct-reading instrumentation (Figure 7–2).

In this way, a much greater number of samples and much more information can be obtained and evaluated immediately. Data loggers are used to obtain a continuous record of concentration. The data may be analyzed by programs resident in the instrument itself, or downloaded to a computer for further analysis. Standard features include

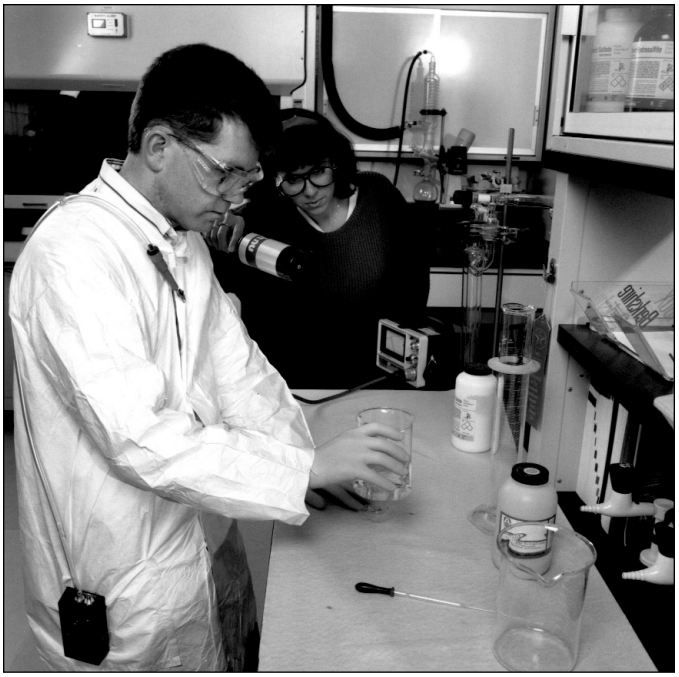


Figure 7–2. The industrial hygienist assesses the degree of risk in the workplace based on the toxicity of the substance, the concentration in the breathing zone, the manner of use, the duration of the exposure, the controls already in place and their effectiveness, and any special susceptibilities of the employees in the workplace. (Courtesy Fermilab Visual Media Services.)

plots of concentration over time and calculations of time-weighted averages over specified time periods. Peak concentrations are readily observed from these graphs; such peaks would have been obscured with integrated samples such as charcoal tubes. Peak concentrations are especially important when the vapor is an irritant or is highly odorous, or if a subjective complaint is involved. The concentration above the norm must be reduced to achieve satisfaction as quickly as possible.

Because correct operation of direct-reading field instruments often requires considerable laboratory backup for maintenance, testing, and calibration, they are not as expedient as they seem. The cost for a field evaluation may be much more than the cost of a laboratory analysis, but this may be offset because much more information is obtained.

See Chapter 15, Evaluation, Chapter 16, Air Sampling, and Chapter 17, Direct-Reading Instruments for Gases, Vapors, and Particulates for more information.

CONTROL OF HAZARDS

Responsibility of Health and Safety Personnel

Personnel concerned with health and safety should recognize that the use of toxic gases and solvents can be a major threat to health and that hazard assessment and control are necessary to prevent detrimental physiological effects.

Exposure evaluation and workplace inspection should be a routine part of any health and safety program. Exposure evaluations should be performed for new processes to ensure that controls are adequate to protect workers. Surveys or searches should also be made for evidence of disease. Dermatitis, unusual behavior, coughing, or complaints of irritation, headache, and ill feeling are all outward signs of potential disease that warrant further investigation. Positive findings justify the effort and provide convincing evidence for educating personnel to the need for corrective actions.

Note conditions and practices that contribute to excessive exposure and call them to the attention of responsible personnel. Train users to handle chemicals properly to prevent injurious exposures. Set guidelines to direct operating personnel in the selection, use, and handling of chemicals. Prohibit general use of highly toxic chemicals, highly flammable solvents, or solvents that are extremely hazardous, unless special evaluation or authorization is obtained.

Finally, provide technical assistance to help the user select the least hazardous chemicals, design and obtain proper ventilation, eliminate the risk of fire, eliminate skin contact, and evaluate situations when workers might be exposed to excessive levels.

Process Controls

SELECTION OF CHEMICALS

One of the most effective means of controlling chemical exposure is to use the least hazardous material. By simply substituting a less toxic or less volatile solvent, for example, one can minimize or eliminate a hazard. The fact that a certain chemical has been specified does not mean that it is the only one or even the best one for a particular use. At times, the one specified is the most familiar one.

This fact is more apparent if one compares the TLVs and the vapor pressures or distillation ranges of different solvents in each class. Toluene and xylene are solvents that can usually be substituted for benzene, for example. If an aromatic hydrocarbon is not required, then it can be replaced with less toxic aliphatic mineral spirits. Low-molecular-weight glycol ethers are used in semiconductor manufacturing processes as a solvent for photoresists, but higher-molecular-weight analogues that have little, if any, reproductive toxicity can be suitable in some situations. The potential for fire can be minimized by the introduction of nonflammable 1,1,2-trifluoro-2,2,1-trichloroethane or 1,1,1-trichloroethane.

The best all-around solvent is water. It is nontoxic and nonflammable and (with the proper additives) it forms an aqueous solvent system that is a good solvent for many organic materials. For the cleanup of inorganic soils, aqueous solvent systems are still the best. The disadvantages are corrosivity of many aqueous solutions and the slow evaporation rate of water. Also, additives may leave a residue on a manufactured item, necessitating further cleaning.

Aliphatic hydrocarbons are good for dissolving nonpolar organic materials such as oils and lubricants. The aliphatics,

however, are not effective cleaners for dissolving or removing many tenacious inorganic materials.

Aromatic hydrocarbons are especially effective on resins and polymeric materials. Between the aromatic and aliphatic hydrocarbons in solvent power are the cyclic hydrocarbons. Halogenated hydrocarbons are effective solvents for a wide range of nonpolar and semipolar compounds.

The nitrohydrocarbons have not been used to a large extent as cleaning agents. Their greatest use has been as solvents for esters, resins, waxes, paints, and the like. Because the ketones, alcohols, esters, ethers, aldehydes, and glycols are more water soluble than the other classes, they are good solvents for the more polar compounds. These solvents are often used as cleaning agents alone or combined with other solvents, especially water. They are useful as solvents for paints, varnishes, and plastics.

Remember that for nearly every process there is an effective solvent or solvent blend that has low toxicity and low flammability. For example, several companies have switched to water containing an alkaline cleaner as a replacement for naphtha and other such organic solvents for cleaning hydraulic tubing, tanks, and other containers. Inhibited 1,1,1-trichloroethane has replaced carbon tetrachloride as a household spot remover. As a guide, the following suggestions might be used:

- ➢ Use an aqueous (water) solution if possible.
- ➢ When possible, consider a different process altogether, one that does not involve chemicals.
- ➢ Solvents that are toxic are to be used only with properly engineered local exhaust systems. Solvents such as trichloroethylene, toluene, and ethylene dichloride are in this category.
- ➢ Highly toxic or highly flammable solvents, such as benzene, carbon tetrachloride, and gasoline, should be prohibited as general cleaning solvents.

Definite dividends will result from this policy. The number of employees who might have exposures exceeding the TLV can be reduced significantly. The number of small fires resulting from the use of flammable bench solvents also can be reduced.

Engineering Controls

ENCLOSURE AND VENTILATION

The major route of entry for chemicals into the body is the lungs (see Chapter 2, The Lungs). The lungs have a surface area of about 85,000–115,000 sq in. (55–75 m^2); much of this area is permeated with thin-walled capillaries. Chemicals in the breathing zone are drawn into the lungs during breathing, quickly absorbed into the bloodstream, and distributed to other parts of the body. The most effective way to prevent inhalation of gases and vapors is to keep them out of the breathing zone. This is done by using closed systems and local exhaust ventilation. All open vessels should be kept covered except when in use. Systems should be designed to prevent leakage and spillage and to collect and contain the solvent in the event of a leak or spill. Proper ventilation must be installed for any process using solvents. Even storage areas require adequate general ventilation to prevent accumulation and buildup of flammable or toxic concentrations. (See Chapters 19 through 21 on industrial and general ventilation.)

If subambient temperature storage of solvents is recommended, they should be stored only in refrigerators constructed and designated for that use (explosion-proof or explosion-safe). Such refrigerators have had their ignition sources removed. Refrigerators used for storage of food and beverages should not be used for any other purpose.

Local exhaust ventilation is necessary to capture the vapors at their point of origin and thus prevent excessive concentrations in the breathing zone. If a highly toxic solvent or gas is being used, or if general ventilation is poor, a local exhaust system, completely enclosing the process, or both is necessary to remove the vapors. All control measures should maintain concentrations of hazardous chemicals in the breathing zone well below the OSHA-specified levels. Present trends in worker's compensation insurance and federal regulations justify designs that are well on the safe side. Ventilation systems are a topic in themselves and the reader should refer to Chapters 19 through 21 and to the ACGIH Industrial Ventilation Manual or American National Standards Institute (ANSI) series Z9 standards on industrial ventilation (see Bibliography). Remember that the local exhaust ventilation system of removing vapors at their point of origin is usually the most satisfactory means of control.

Personal Protective Equipment

RESPIRATORS

Do not use respirators as the primary or only means of protection against hazardous chemical vapors because too many factors limit their use. They can be used as emergency or backup protection. Respiratory protective equipment, especially the air-purifying type, is limited by leakage around the mask edges, surface contamination, impaired efficiency with use, and need for adequate oxygen. Unless it is correctly used and properly cared for, a respirator may present a greater danger to an employee than no protection at all. Too often, such equipment gives a false sense of security and the wearer becomes careless and may be exposed to highly hazardous levels. Respirators should be controlled through a program that provides for proper selection, fitting, testing, education, and maintenance under the surveillance of competent personnel. Such a program is mandatory under present federal occupational safety and health standards. (See Chapter 22, Respiratory Protection.) Make sure that the level of gases or vapors in the air does not exceed the protective factor of the respirator. Air-purifying respirators should not be used for operations where the solvent is air-sprayed unless there is supplementary mechanical ventilation. OSHA has issued a new respirator standard; among the new requirements is one in which the employer must develop a schedule for changing cartridges and canisters for air purifying respirators. See Chapter 22 for more details.

PROTECTIVE CLOTHING AND GLOVES

Another major route of entry for hazardous chemicals is through the skin. Dermatitis is the leading industrial disease, and solvents are second only to cutting oils and lubricants in causing this disease. (See Chapter 3, The Skin and Occupational Dermatoses.) Skin contact occurs through direct immersion, splashing, spilling, contact with chemical-soaked clothing, improper gloves, and contact with solvent-wet objects. Some solvents such as benzene, carbon tetrachloride, and methyl alcohol can be absorbed in amounts great enough to cause physiological injury to organs other than the skin. The most effective way and often the only way to prevent harm is to keep the solvent from the skin. This can be done by using mechanical handling devices, such as tongs and baskets, and by using impermeable protective clothing, such as aprons, face shields, and gloves.

The use of gloves requires caution. A common mistake is to recommend "rubber" or neoprene gloves for use as hand protection against a solvent, regardless of the kind of solvent in use. Many solvents can quickly penetrate latex rubber or neoprene gloves and come in contact with the skin.

The permeability of gloves to certain solvents and chemicals is the most important characteristic to consider when selecting gloves for protection. Chemical manufacturers include permeability information with their product, often in the form of permeability tables or computer software for glove selection. They suggest appropriate glove materials for particular chemicals. The abrasion resistance of glove materials is also given in tables and this information is often more widely available. Note both permeability and abrasion resistance when considering the type of gloves to use with certain solvents.

Permeability measurements should be made on the complete glove if the effect of weak or thin spots is to be detected. A rough comparison of the permeability of gloves plus an indication of some of the other characteristics can easily be made by turning the gloves inside out, filling them three-fourths full of solvent, sealing the cuff, and measuring the loss of weight, the stretch, and other parameters.

More precise methods for measuring glove permeability are available, but require the use of an analytical laboratory. A standard method has been published by the American Society for Testing and Materials.

The time required for a chemical to penetrate a glove is affected by the glove's thickness and its composition. In some cases, the time to break through can be as brief as five minutes. For example, it has been shown that benzene breaks through a 0.03-mm polyethylene glove in five minutes. Conversely, the same glove material had a two-hour breakthrough time when tested against butyl acetate.

Note that gloves made of the same material and nominal thickness, but from different manufacturers, may have significantly different breakthrough times. This difference may result from differences in formulation of glove materials or manufacturing procedures used.

Neoprene is good for protection against most common oils, aliphatic hydrocarbons, and certain other solvents, but is not satisfactory for use against the aromatic hydrocarbons, halogenated hydrocarbons, ketones, and many other solvents. Natural rubber is not effective against these solvents.

Polyvinyl alcohol (PVA) gloves provide adequate protection against the aromatic and chlorinated hydrocarbons, but they must be kept away from water, acetone, and other solvents miscible in water to prevent deterioration. Butyl rubber gloves can be a suitable compromise when polyvinyl alcohol cannot be used.

Regular periodic cleaning and drying of gloves is as important as using the proper type. Keep an extra pair of gloves available for use while the cleaned pair is being aired and dried. When the gloves become soiled with hard-to-remove hazardous materials such as insecticides and epoxy resins, it is often better to discard the glove than to try to clean it. In some situations, gloves must be replaced after only a few minutes' work. If the outside of any glove becomes thoroughly wetted, remove it promptly.

Disposable gloves are useful for light laboratory or assembly work, but are too easily torn or punctured for heavier work. Latex medical gloves provide good manual dexterity, but they tear easily and are permeable to many solvents. Their use is not recommended in an industrial setting. If they are used, an effective practice is to change immediately after a splash or contamination or change gloves frequently even if direct contact has not occurred. There is no set recommendation for the use of gloves; what works well for one group of workers may not work for another. In many cases, a certain amount of trial and error is required. Gloves are subject to small tears that may go unnoticed, but drastically reduce their efficiency. Gloves may also increase the absorption of solvents if they do penetrate the glove, and the solvent is then trapped in close contact with the skin and cannot evaporate.

Barrier creams are the least effective way of protecting skin. Barrier creams are not a substitute for gloves, except when there is only occasional and minor contact with a solvent, or around rotating machinery when gloves cannot be worn because of the catching hazard. Barrier creams are *not* as effective as an impervious glove. (See Chapter 3 for more information on barrier creams.)

Good personal hygiene is important whenever chemicals are used. Remove spills and splashes from skin immediately with soap and water. This includes showering and replacing solvent-soaked or splattered clothing with clean clothing immediately and as often as necessary.

PROTECTIVE EYEWEAR

Workers at risk for a splash of chemicals in the eyes must wear appropriate protective eyewear. It must be noted that protective eyewear should not be used as the sole protection, but in conjunction with engineering control, guards, and good manufacturing practice. OSHA, in 29 *CFR* 1910.133, requires eye and face protection when injury can be prevented by its use.

The standard practice is given by ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection.*

For chemical splash or irritating mists, eye protection should be selected from unvented chemical goggles, indirect-vented chemical goggles, or indirect-vented eyecup goggles. Direct vented goggles and spectacle-type eye protection do not provide protection against liquid exposures and should not be used. For severe exposures, a face shield should be used in conjunction with goggles; a face shield by itself does not provide adequate protection against liquid splashes. Where both an inhalation and splash hazard exists, full-face respiratory protection is preferable over a half-mask and goggles.

Traditionally, the recommendation has been that contact lenses should not be worn in eye hazard areas. However, the new ANSI standard removed the prohibition on contact lenses. (See Chapter 5, The Eyes, for more information.)

SUMMARY

Critical exposure factors include how the material is used and what controls (engineering or personal protective equipment) are in place, temperature and volatility, concentration, and reactivity. Guidelines for exposure are discussed. In this chapter, solvents are classified as aqueous or organic systems. Gases as cryogenic liquid and simple and chemical asphyxiants and their characteristics are discussed. Flammable and combustible liquids, flash points, flammable range, and requirements and guidelines are given. The physiological effects of aqueous systems, organic compounds, aliphatic hydrocarbons, cyclic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, nitrohydrocarbons, oxygen-containing functional groups, inorganic acids, and organic and inorganic gases as well as hazard potential, evaluation, and control are covered.

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Chapter 8

Particulates

by Richard J. Kelly, MS, CIH

Particulate matter is probably the type of environmental chemical hazard most on the minds of U.S. citizens. Lead in paint, asbestos in schools, radon progeny in homes, Hanta virus in sheds, and diesel smoke are all current issues in the lay press. Industrial hygienists see many other emerging particulate matter issues, including exposures to beryllium, free crystalline silica, endotoxins, toxic fungal spores, and cadmium.

The objective of this chapter is to familiarize the reader with the basic concepts of anticipating, recognizing, and evaluating occupational particulate matter hazards. Basic concepts of aerosols, aerosol behavior, sampling, analysis, filtration, lung deposition, and biological responses are introduced, with many specific examples discussed in detail and within a historical context. Regulatory and consensus guidelines are reviewed whenever appropriate. Air, surface, bulk, dermal, and biological sampling are described, and the relative roles of each are discussed. Many tables that will provide quick reference for common particulate matter concerns are included. An extensive bibliography is provided, including sources for equipment, sampling tools and supplies, and reference materials.

BACKGROUND

In the field of industrial hygiene, *particulate matter* (*PM*) is traditionally defined as small (less than 100 micrometers in diameter) pieces of solid materials, liquid droplets, or microbiological organisms. On the other end of the spectrum, particles smaller than about 0.001 µm start to act like gases, and thus are not treated as particulate matter. This range of particle sizes under consideration is five orders of magnitude. The adjective *particulate* is often used as a noun in the industrial hygiene literature in lieu of the full term "particulate matter" (PM). While this is incorrect English, it is common enough that it is generally accepted "jargon" in the occupation.

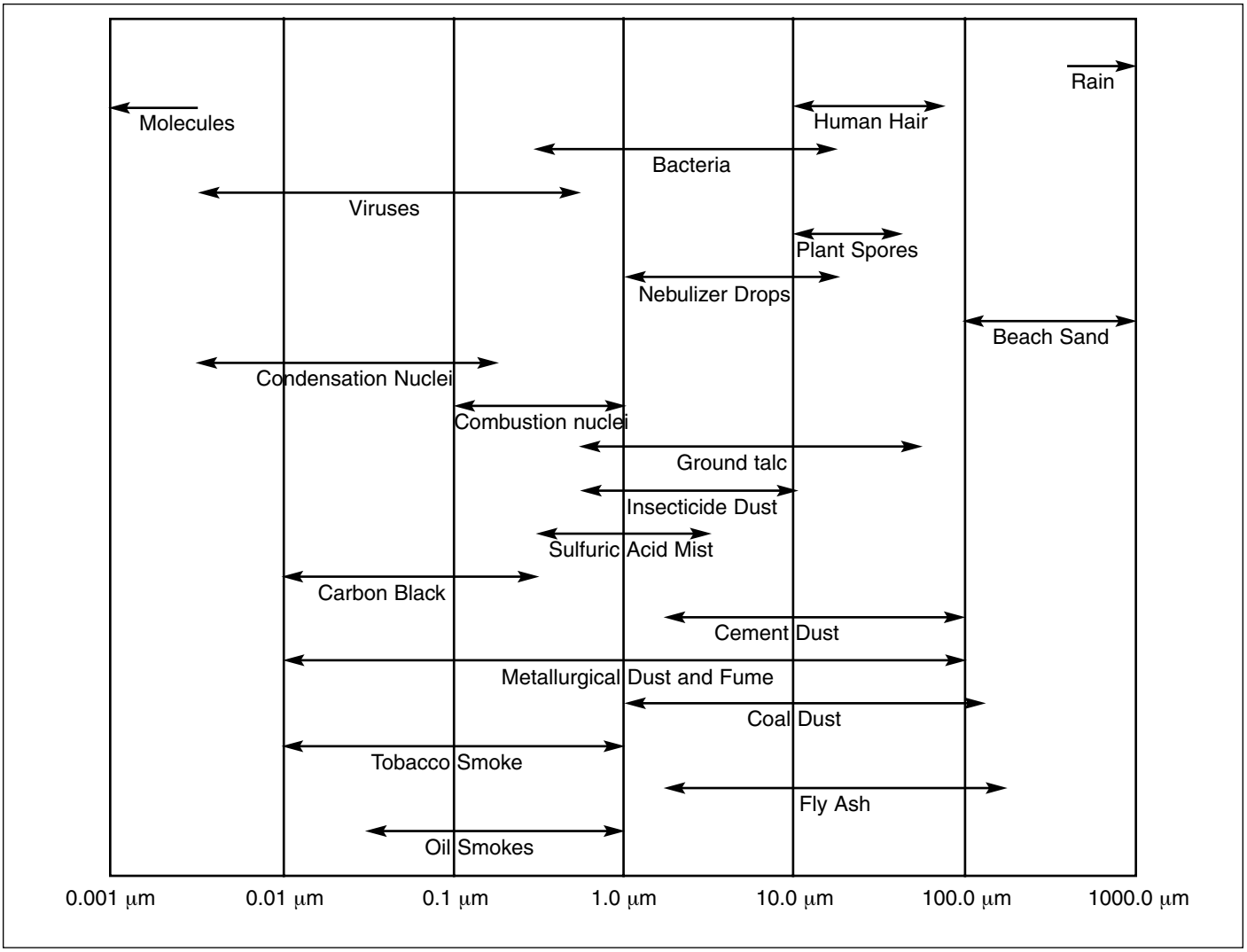

Figure 8–1. Size range of various particulate matter clouds.

Most often, particulate matter is regarded as a hazard when suspended in air, forming an *aerosol,* which can then be inhaled. Only particles less than approximately 100 micrometers in diameter have the potential to remain suspended in the air for any length of time to form a hazardous aerosol. Indeed, the primary route of exposure for most hazardous particulate matter is inhalation, with toxicity occurring subsequent to removal of the particulate matter from the aerosol by deposition in the lungs. Substantial exposure to particulate matter can result in a wide variety of biological responses ranging from acute to chronic and mild to life-threatening. Figure 8–1 represents the size range of different types of occupationally significant particles.

The hazards associated with occupational inhalation of aerosols have long been recognized. Pliny the Elder (AD 23–79) wrote of lead inhalation hazards during scraping of lead-containing paint. Agricola (1491–1555) and Ramazzini described the hazards of aerosols in mining, and they were a major topic of writings by Alice Hamilton as the industrial revolution flourished and the field of industrial hygiene evolved in the very early 20th century.

While exposure to particulate matter as an aerosol is the most common route, some types of PM may be hazardous by ingestion or skin contact. Sir Percival Pott identified cancer caused by skin contact with soot among chimney sweeps as early as 1775. Lead particles that have settled out of the air onto eating surfaces can be absorbed through the gastrointestinal tract to cause systemic poisoning. Recently it has been suggested that chronic beryllium disease may be triggered by contact of insoluble beryllium-containing dust with the lips, mouth, or even eyes. Thus, the range of potentially hazardous routes of exposure posed by particulate matter is broader than often recognized.

The least toxic airborne particles have been traditionally classified as "nuisance dusts," or more recently by the American Conference of Governmental Industrial Hygienists as "*Particulates* (*insoluble*) *Not Otherwise Classified* (*PNOC*)." OSHA has a somewhat parallel term, *Particulates Not Oth-*

Table 8–A. ***General Types of Particulate Matter (PM)***

Type of PM	*Sub-Type*	*Defining Characteristic*	*Examples/Sources*
Dusts	General	Produced by mechanical action on larger pieces of the material (e.g., grinding, cutting, tearing)	Lead dust while scraping paint Quartz dust when jack hammering
	Fibers	Dust classified because of its shape as long thin tendrils	Asbestos Ceramic fibers Fiberglass
	Biological (not micro-organisms)	Typically organic dusts created by disturbance of plant or animal materials	Wood dust Cotton dust Animal dander
	Radioactive	Radiotoxicity is often more significant than chemical toxicity	Radon progeny Radioactive waste Uranium
Mists	General	Droplets of liquid. Always defined in the context of an aerosol. Created by mechanical action breaking liquid into small particles	Droplets from bubbling dip tanks Paint overspray
	Fog	Droplets of liquid caused by recondensation of vapor	Boiling acids in chemical digestion
Fume	All	Formed by the evaporation and rapid condensation of metal vapor into very small particles	Welding Arc or torch cutting Foundry work
Biological agents	All	These include living and non-living agents that may be allergenic, toxigenic or infectious	Bacteria (and related organisms) Viruses Fungal spores Prions
Smokes	All	Smokes are the products of incomplete combustion of organic materials. Created by vaporization of organic material with subsequent condensation. Sometimes used interchangeably with "fumes"	Diesel exhaust Coke or coal powered furnaces Human tissue during laser surgery Second-hand cigarette smoke

erwise Regulated (*PNOR*). As implied by the older nomenclature, these particles are supposed to cause only minor health effects at relatively high exposures, leaving no important long-term lung damage or impairment. In fact, until the 1980s this nomenclature was directed almost exclusively toward pneumoconiosis-producing dusts. The current ACGIH definition is broader, adding reference to particles which will not have a systemic effect.

Particulate matter typically encountered in the occupational environment can be divided into a number of "types," based primarily on how the PM was created, its shape, and its composition. Table 8–A lists the broader classifications and some subclassifications of PM.

There are thousands of types of inorganic and organic particulate matter that may be found in the occupational environment. Table 8–B lists some of the more ubiquitous PMs, as well as certain types of PMs that are of current special interest in industrial hygiene and air pollution.

Many of the classic chronic respiratory tract diseases that have been attributed to inhalation of PM result in a type of illness that is broadly called a *pneumoconiosis*. Derived from Greek, this simply means "dust in the lungs." This term has been rather widely used to describe a number of lung diseases, many of which do not share mechanisms, symptoms, or prognoses. Some "diseases" classified as pneumoconiosis are not known to result in any clinical symptoms, whereas others are potentially fatal as a result of the formation of collagenous fibrotic scarring. Some are reversible upon cessation of exposure, some often remain stable if exposure is stopped, and others may progress even without further exposure.

Attempts to define pneumoconiosis were made as early as 1916. There was no universally accepted definition of pneumoconiosis until 1950. A more recent definition of pneumoconiosis is "the accumulation of dust in the lungs and the tissue reaction to its presence." This assumes that the dust is solid and relatively insoluble when deposited in the alveolar region of the lungs.

Classically, the severe forms of pneumoconiosis are associated with lung fibrotic changes. Different exposures result in distinct patterns of fibrosis on chest x-ray images. There are several defined subforms of fibrosis associated with pneumoconiosis, including hyaline-nodular fibrosis pneumoconiosis, coal miners pneumoconiosis, mixed dust pneumoconiosis, and diffuse interstitial fibrotic pneumoconiosis. Interpretation of chest x-ray films for signs of pneumoconiosis is a complex specialty, and such trained physicians are referred to as "B" readers.

Table 8–C lists many of the agents that have been associated with a type of pneumoconiosis.

Table 8–B. ***Selected Hazardous Particulate Matter***

Agent	*Typical Industries/Occupations for Exposure*	*Summary of Health Effects*
Arsenic and inorganic compounds	Agriculture; wood treatment; semiconductor wafer fabrication (gallium arsenide); alloy production; pesticide manufacture; lead smelting	Inhalation of inorganic arsenic compounds can cause chronic poisoning with weakness, nausea, respiratory tract symptoms and damage to the peripheral nervous system; cancer
Asbestos	Asbestos abatement; demolition; building maintenance; custodial work; brake repair and replacement	Inhalation increases the risk of lung cancer, mesothelioma (a cancer of the lining of the lungs and peritoneum), asbestosis
Bacteria	Office work; hospitals; sewer repair and maintenance; biological research; social service industries; grade school teaching	Exposure to airborne bacteria may cause indoor air quality problems, humidifier fever, alveolar inflammation or infection.
Beryllium and compounds	Aerospace; nuclear industries; electronics; mining and processing; tool manufacturer; refractory ceramic industries; chemical research; sporting goods manufacturing; machining	Chronic exposure to beryllium metal, oxides, and other insoluble compounds may cause "chronic beryllium disease" and cancer. Very high exposure to soluble compounds may cause acute beryllium disease
Cadmium and compounds	Metal brazing; alloy making; welders; metal coating; construction	Acute exposure may cause potentially fatal pulmonary edema. Chronic exposure may cause systemic illness or cancer
Chromium and compounds	Metal plating; chemical research; welding; stainless steel production and use; machining	Chromium in the hexavalent oxidation state is the most toxic. Exposure may be to dust in some operations and mist in electroplating. Exposure to chromium hexavalent compounds may cause a range of irritation effects, allergic sensitization, and lung cancer
Cotton (primary)	Cotton and flax workers	Byssinosis, which results in progressive difficulty in breathing, probably caused by an allergic or pharmacological agent in the bract associated with fresh cotton
Cobalt and compounds	Alloy making; pigment manufacture; machine tool sharpening; electroplating; aerospace; blue glass manufacturing	Inhalation may cause asthma-like illness, which may progress to fibrosis. A specific form of pneumoconiosis associated with cobalt and some other metals, especially metal carbides, is called "hard metal disease"
Diesel exhaust	Operation of diesel powered industrial trucks; toll takers; construction	Potential increase in asthma and lung cancer
Isocyanates (e.g., TDI, MDI, HDI)	Paint sprayers; polyurethane manufacturing; organic chemical synthesis; construction	Effects range from transient irritation of the respiratory tract to chronic sensitization and reduction in lung function. Exposure may occur as a mist or vapor
Lead and compounds	Painting; demolition; lead abatement; battery manufacture and maintenance; welding and cutting; brazing; building maintenance; radiation users; machining	One of the most common industrial illnesses is chronic lead poisoning, which damages the peripheral and central nervous systems, sometimes irreversibly
Manganese and compounds	Steel manufacturing; alloy making; paint manufacture; chemical research	Inhalation may cause severe damage to the central nervous system, sometimes mimicking Parkinson's disease
Mold (fungal) spores	Office work; farming; biological research; mining; earth-moving trades (geographically specific); grain milling; migrant farm work; cotton mill workers; silo operators; saw mill operations; mushroom farming; cork production; sugar cane harvesting	Exposure to mold spores may cause allergy (hypersensitivity reaction), poisoning (if the spores contain mycotoxins), or infection. Some spores infect healthy hosts; others infect mostly compromised hosts. A combination of these responses is possible
Nickel	Nickel refining; stainless steel manufacture; alloy production; welding and cutting; chemical research; electroplating; battery manufacture; machining	Nickel and some compounds are probable human respiratory tract carcinogens. Other systemic toxicity has been reported
Pesticides	Pesticide manufacture; pesticide application; farming; gardening; fumigation	There are a wide variety of pesticides with varying toxicity. Many former pesticides have been banned either because of toxicity or biopersistence. One common class, the organophosphates, can cause damage to the peripheral and central nervous system as well as a host of other body systems

(Continues)

Table 8–B. ***Selected Hazardous Particulate Matter (Concluded)***

Agent	*Typical Industries/Occupations for Exposure*	*Summary of Health Effects*
Radon progeny	Mining; work in underground vaults; work at homes with cellars or concrete office buildings	Radon is a radioactive gas, but when it decays it forms single ions of other radioactive species that bind electrostatically with other dust to form radioactive particles
Silica-quartz, cristobalite and tridymite	Sand blasters; concrete demolition; building demolition; hard rock mining; building maintenance; cement manufacture	Exposure to these specific crystalline forms of silicon dioxide typically produces a chronic lung nodular fibrosis called "Silicosis" which impairs lung function. This effect can occur in a matter of months at very high exposure levels
Sodium hydroxide	Electroplating; chemical metal cleaning; metal etching; plastic production; soap manufacture; chemical laboratory work	Sodium hydroxide is not volatile, so all exposure occurs to the dust or mist. These are extremely alkaline and may cause local tissue irritation or destruction
Thallium and compounds	Pesticide manufacture; pesticide application; chemical laboratory work; optics fabrication; alloy making	Thallium is very toxic and the effect is cumulative. Early symptoms of exposure include fatigue and myalgia, with later symptoms including those associated with nervous system damage
Thorium and compounds	Gas mantle fabrication; alloy making; welding rod production; welding; chemical laboratory work; ceramic production	The main hazard posed by this material is due to the accumulation of the radioactive thorium. Although not a high activity material, it still must be controlled due to its radioactivity
Uranium and compounds	Uranium mining; nuclear industries; uranium refining; uranium fuel reprocessing; uranium enrichment; low levels may also be present in other rare earth compounds	Naturally occurring uranium is a mixture of three isotopes. The isotopic ratio does not affect the chemical toxicity but influences the radiotoxicity. Soluble uranium compounds pose the highest toxic hazard and generally the lowest radiohazard. The target of the chemical toxicity is the kidney. Radiotoxicity increases the risk of cancer
Wood dust	Saw milling; lumbermen; furniture makers; carpenters	Depending on the wood, inhalation of dust may cause toxic, irritant, or allergic effects. Severe sensitization can occur in some cases, notably with mahogany and western red cedar. Inhalation of some hardwood dusts may contribute to nasal cancer.
Zinc oxide fume	Welding; torch or arc cutting—all where zinc is present	Most common metal fume associated with "metal fume fever," a transient flu-like illness occurring 2-24 hours after exposure and lasting hours to several days

BASIC CONCEPTS, PROCEDURES, AND EXAMPLES

Particle Deposition Mechanisms

When a particle passes through a filter and is not effectively removed from the aerosol, the filter has failed to do its job. When a particle is inhaled but is subsequently exhaled without deposition in the respiratory tract, it will have no toxic effect. If it is deposited in the lung, *where* it is deposited may determine if it will contribute to an illness. When attempting to collect a particle for analysis, if it is not deposited on the filter or other sampling medium, the sampling effort will be inaccurate.

The removal of a particle from a moving aerosol is called particle deposition. There are five primary mechanisms of particle deposition, and they are all applicable to filters, lungs, sampling media, or any other surfaces that are exposed to a moving aerosol.

1. *Inertial impaction*—As a particle moves within an aerosol, it gains momentum that is proportional to its mass. The individual atoms or molecules of the gas phase of the aerosol effectively have no momentum. When a moving gas phase of an aerosol is forced to change direction abruptly, it does so, albeit with the possible formation of eddies and turbulence. However, a particle with significant mass and inertia follows Newton's Law that states "a mass in uniform motion tends to remain in motion unless acted upon by an outside force." Thus, while the gas responds very readily to abrupt changes in direction, the particle

Table 8–C. ***Agents Associated with Pneumoconiosis***

Asbestos (asbestosis)	Aluminum w/silica (Shaver's disease)	Beryllium (chronic beryllium disease)
Barium	Bentonite	Cement
Cerium	Coal (black lung)	Diatomite
Fullers earth	Hematite	Iron (siderosis)
Kaolin	Mica	Mixed dust
Silica (silicosis)	Tin (stannosis)	Titanium

tends to resist this change in direction and deviate from the air stream. This may cause the particle to *impact* on the surface, stick there, and be removed from the aerosol. Impaction is directly proportional to the density of the particle, the square of its diameter, and the velocity of the moving aerosol. It is most effective for large and dense particles in high velocity air. It is a common principle used in the collection of industrial hygiene PM samples.

2. *Interception*—Particles not deposited by inertial impaction may be deposited by interception. In this case, the particle follows the air stream fairly well (because it is small, of low density, or in a more slowly moving air stream), but still contacts the surface of the filter or lung. It sticks, and has effectively been removed from the aerosol. Interception is most effective for mid-sized particles. A special case of interception, sieving, is an important deposition mechanism for very large airborne particles.
3. *Sedimentation (Settling)*—All particles are acted upon by gravity and tend to move toward the center of the earth. If the particle settles onto a surface, it may stick and be removed from the aerosol. In a vacuum, the particle would accelerate continuously until it reached the surface, independent of its mass or shape. In the real world, particle movement is resisted by aerodynamic drag created by the particle moving downward through the gaseous phase, and convection upward within the gaseous phase. In a still environment, where drag is the primary force resisting sedimentation, the terminal rate of settling (Vt) for most particles can be can be estimated by Equation 1, which combines Newton's Second Law of gravitational acceleration with Stokes' Law pertaining to drag forces of particles moving in a viscous medium. When the increasing particle velocity creates a drag equal and opposite to the force imposed by gravity, the particle attains its terminal settling velocity.

   The effectiveness of sedimentation in a still aerosol is proportional to the particle's mass, and large particles settle out much faster than small particles.

Equation 1

$$Vt = \frac{(\text{particle density})(\text{gravity})(\text{Cunningham correction})(\text{diameter}^2)}{18\ (\text{air viscosity})\ (\text{dynamic shape factor})}$$

The terminal settling velocity (Vt) in centimeters per second is found when:

- ➢ Particle density is in grams per cubic centimeter
- ➢ An average value of the gravitational constant in CMS units of 980 cm/second^2
- ➢ Particle diameter is in centimeters
- ➢ Standard air viscosity can be assumed to be 1.8 x 10^{-4} g/(cm • s)
- ➢ Cunningham correction factor is looked up (unitless)
- ➢ The dynamic shape factor is looked up or approximated from Table 8–D (unitless)

4. *Electrostatic attraction*—Charged collection surfaces will tend to attract and hold oppositely charged particles. Most airborne particles carry some net charge, and can be effectively removed by electro-attractive forces if presented with a surface with the opposite net charge. While not known as a major mechanism of deposition in the respiratory tract, some air filters are designed to hold sustained electrostatic charges, and this can greatly increase the efficiency at which they remove particles from aerosols. Also, some industrial hygiene sampling methods still use electrostatic attraction to collect particles, and unintended electrostatic effects hamper other sampling methods.
5. *Diffusion* (*Brownian movement*)—Very small particles do not see the gas in which they are suspended as a continuum. Instead, they react to individual atoms of the gas or uneven impact by groups of air molecules over time. As a result the particles wander around in a seemingly random path, an effect termed Brownian motion (or movement). Many people have seen this happen to small bacteria in liquid suspension through a microscope. As the particles flow with the air, they tend to wander from the airflow lines, and may bump into a collection surface and be removed from the aerosol. The effectiveness of diffusion as a deposition mechanism is indirectly related to the square of the particle diameter and to the velocity of the aerosol. Thus, slow movement of small particles favors deposition by diffusion. The six deposition methods are shown diagrammatically in Figure 8–2.

The net deposition of particles on an air-cleaning filter, sampling device, or in the lungs is almost always the result of action of two or more of these deposition mechanisms. Figure 8–3 shows the relative contribution of many of these mechanisms to collection of particles on a specific filter, as a function of both effective aerodynamic diameter and aerosol flow velocity. It is evident that impaction becomes of increasing importance as both particle size and air flow rate goes up, gravitational settling predominates for larger particles at low flow rates, and diffusion is the only active mechanism for particles less than 0.1 µm, regardless of the flow rate.

As might be expected, there is a particle size range that is least efficiently collected because none of the deposition mechanisms are highly effective at that size. The exact nadir point in the collection efficiency of a filter varies somewhat with the flow velocity and filter type, but generally lies

Table 8–D. ***Dynamic Shape Factors***

Shape/Type	Typical Dynamic Shape Factors
Sphere	1.0
Cubic	1.08
Clustered spheres (e.g., aged fume)	1.15
Quartz particles	1.36
Talc particles	2.04
Fibers	<<1.0

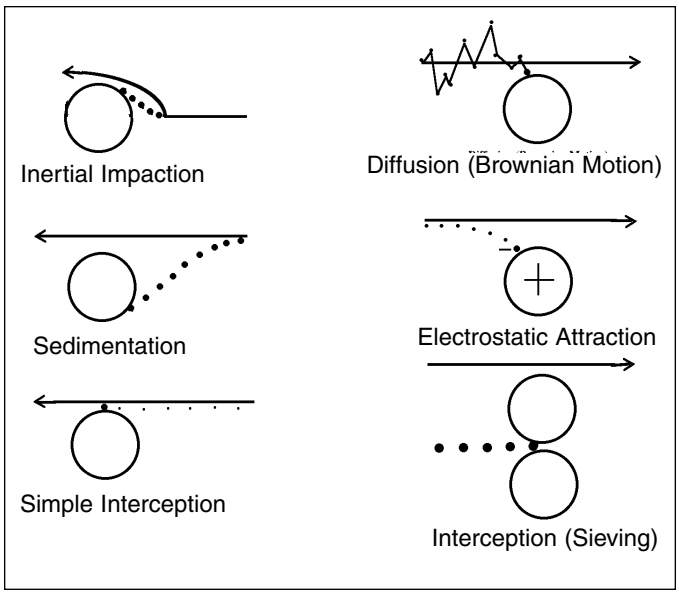

Figure 8–2. Particle deposition mechanisms.

between about 0.1 and 0.4 μm in aerodynamic equivalent diameter. Historically, high efficiency particulate air (HEPA) filters, developed to support nuclear material production facilities and used extensively in respirators, have been tested and certified at a presumed nadir point of 0.3 μm using a narrowly dispersed mass of dioctylphthalate oil droplets. Better understanding of filtration principles and improvements in technology allow some filters, such as *ultra high efficiency air* (*ULPA*) filters to be tested using a nearly monodisperse aerosol with an aerodynamic equivalent diameter of about 0.12 μm. At usual flow rates, this is a slightly more challenging test than the 0.3 μm HEPA test.

This low point or nadir in collection filtration occurs because the effectiveness of impaction and interception tails off rapidly below a diameter of about 0.5 μm, and diffusional mechanisms do not become effective until about 0.1 μm. Thus, particles between 0.1 and 0.4 μm are collected inefficiently by diffusion and impaction. This effect for a certain type of air cleaning filter is shown in Figure 8–4.

PARTICLE SIZE DISTRIBUTIONS

Employees are not exposed to single particles, but rather to large masses of particles suspended in air, commonly called a particle cloud. Particle clouds have a variety of characteristics that often must be understood to fully evaluate and control the hazard they may present.

Particle clouds may be fairly monodisperse, consisting mostly of particles that fall within a very narrow size range, or polydisperse, containing a wide range of particle sizes. Fresh welding fume or fog from condensed boiling acid are examples of fairly monodisperse particle clouds. Both of these types of PM result from vaporization and recondensation, which has a tendency to form uniformly sized particles. Fresh welding fume is typically very small, on the order of 0.01 μm in diameter. The fog caused by acid digestion, often called "fume" by chemists, tends to be formed of larger particles, several micrometers in diameter.

The majority of occupational aerosol-generating activities make polydisperse particle clouds. Sand blasting usually leaves some of the large incident particles (>100 μm) unbroken, yet also forms very small fines. The size distribution of particles is very broad. The same is true for many demolition activities, such as concrete breaking, and many construction activities. For a given agent, the distribution of particle sizes can range over several orders of magnitude.

Another characteristic of particle clouds is that they may be unimodal or multimodal, that is, they can have either a single peak when size is plotted against count, or they can have multiple peaks. This may occur with a single agent in a number of ways, or may result from the mixing of several different forms of aerosol clouds. For example, in the case of welding fume, although fresh fume tends to be composed of very small, spherical particles, as the fume "ages" it has a strong predilection to agglomerate or "flocculate" into irregularly shaped, extended, and enlarged groups of small spheres. A person working near the process may be exposed to both larger agglomerates and fine primary fume, a distribution with two peaks.

Alternatively, bimodal or trimodal distributions of particle sizes may occur when several operations are occurring in the same area of a workplace. In a foundry, a pouring location that generates very fine fumes may be located close to a polishing operation that creates mid-sized metal particles and also to a needle gunning operation that forms very large particles. Thus the chemical composition may be the same, but when evaluated with a size-selective instrument, three distinct modes or peaks are detected. More commonly, chemically heterogeneous multimodal particle clouds are found, such as in a machine shop, where large particles of cutting fluid are mixed with mid-sized particles of metal from grinding operations, and with very small particles of organic smoke from an electronic discharge machining operation. Idealized examples of particle cloud distributions are shown in Figure 8–5.

It is unusual to find a normally distributed particle cloud. When you plot the number of particles on the y-axis and the diameter of the particles on the x-axis, it rarely results in a normal, bell-shaped distribution. This is unfortunate, as basic descriptive statistical techniques are easily applied to normally distributed variables. In normal-normal distributions, the mean (which is the same as the mode and median) is the measure of central tendency, and the standard deviation is the measure of the dispersion. A large mean implies that the average particles are large, and a small standard deviation indicates a fairly monodisperse distribution of particle sizes.

If you measure and plot particle sizes found in a polydisperse distribution, the most common picture that emerges is

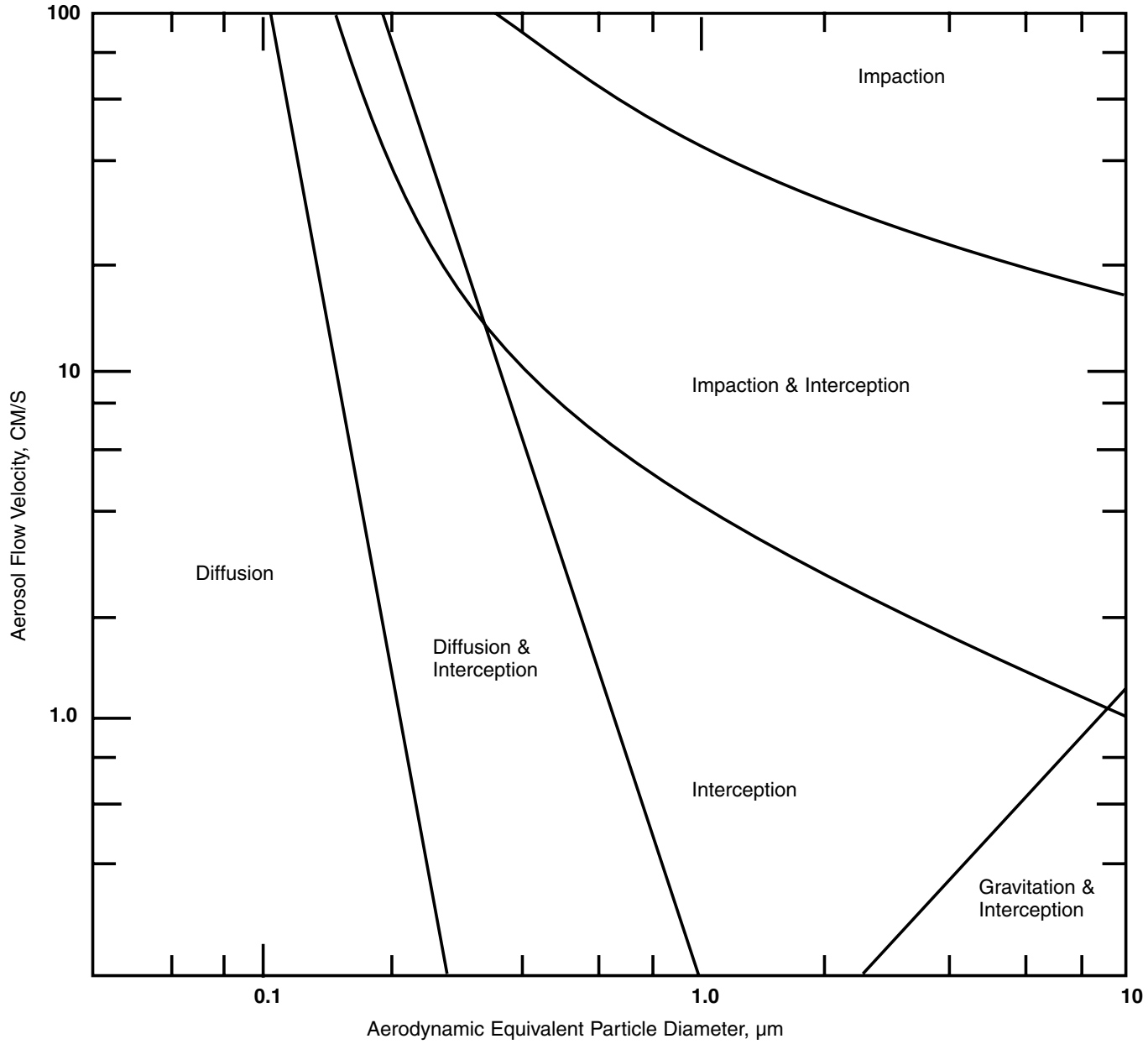

Figure 8–3. Relative contribution of deposition mechanisms as a function of particle size and aerosol flow velocity.

a highly skewed curve, with the majority of particles falling to the right side of the curve (smaller particles), then there is a peak, followed by an elongated, asymptotic slope to the right (larger particle sizes). This may occur for a variety of reasons, including the selective loss by sedimentation or impaction of the larger particles.

Fortunately, it is often possible to convert the skewed distribution into a fairly normal shaped curve by plotting the log of the particle sizes against their count. The resulting distribution, called a *log-normal distribution,* is bell-shaped in appearance and can be described in terms synonymous with those applicable to a normal distribution. The mean of a log-normal distribution is called the geometric mean, and corresponds to the mean in a normal-normal distribution. The geometric standard deviation can be calculated, which is analogous to the standard deviation calculated to define set intervals in normal distributions. The only difference is that instead of adding and subtracting the geometric standard deviation from the geometric mean to define known subsets of the data (as is done in normal-normal distributions), the mean is multiplied or divided by the geometric standard deviation. Thus, a log-normal distribution of a particle cloud with a geometric standard deviation of 10 μm in diameter and a geometric

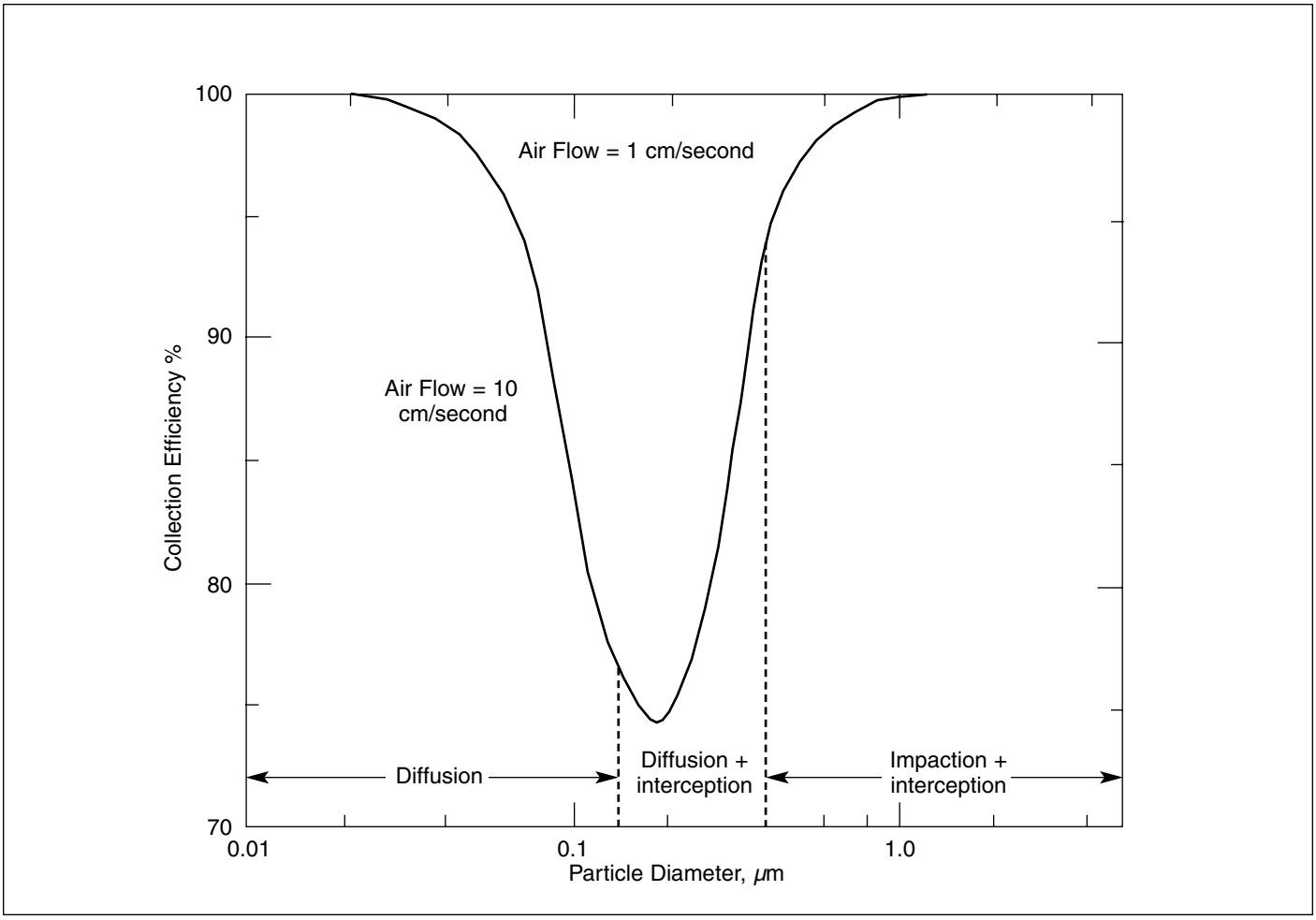

Figure 8–4. Filtration efficiency vs particle size and velocity.

standard deviation of 2 indicates that 67 percent of the particles fall within the size range of 10 x 2 and 10/2, or 5–20 μm. Ninety-five percent of the particles fall within about +/– two geometric standard deviations of the geometric mean, 2.5 to 40 μm. This is a moderately disperse particle cloud.

The geometric mean of a log-normal distribution can be calculated directly, by *log transforming* the data (calculating the $\log_{10}$ of the diameter of each particle), and dividing by the number of particles. It can also be picked directly off a special type of plot, a cumulative log-probability plot. Using this unusual type of graph paper, log-normal distributions plot as straight lines. The geometric mean and geometric standard deviations can be measured directly from this plot, as shown in Figure 8–6.

Sometimes particle clouds are described in terms of the *geometric mass equivalent diameter* instead of the geometric count diameter as described above. This is particularly true when the mass of the particles deposited, rather than the number, determines toxicity. Soluble lead or arsenic compounds are examples of PMs that are toxic when in a soluble form, no matter where they deposit in the respiratory tract. To calculate this, one multiplies the volume of each particle by its mass before plotting or manipulating the data. The geometric mass equivalent distribution has the same geometric standard deviation as the geometric count distribution, but the mean particle size is always much larger than the mean particle diameter of the count distribution. This occurs simply because mass is a third-power function of diameter, and most of the mass in a polydisperse cloud of PM will reside in the larger particles. The extremely fine particles, which appear prominently in the count distribution, are almost irrelevant in the mass distribution.

In contrast, the mass of inhaled asbestos is largely unimportant. It is the count, the number of fibers inhaled, that relates to the probability of developing disease. Thus, the count distribution would be appropriate for the characterization of a cloud of asbestos fibers. Figure 8–6 shows the number and mass distributions of a particle cloud plotted on cumulative log-probability graph paper. Also shown is the surface area distribution, which is not often relevant to the toxicology of the PM, but significant for some types of direct-reading particle enumerators (e.g., forward light scattering photometers).

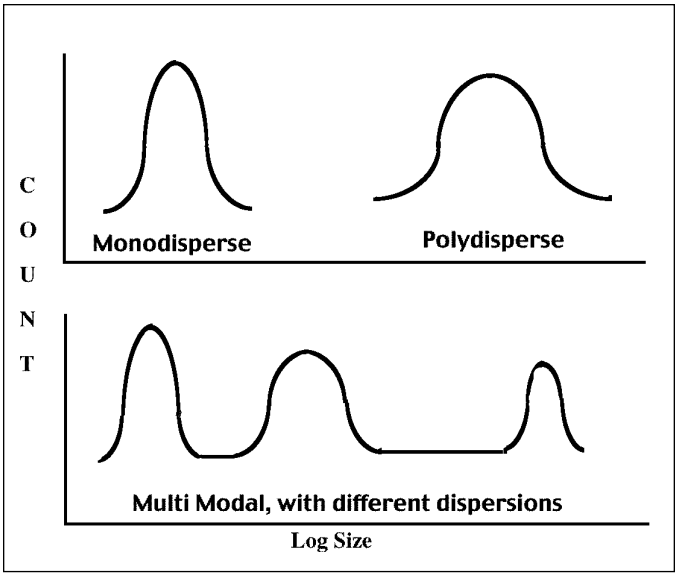

Figure 8–5. Ideal monodisperse, polydisperse, unimodal, and multimodal particulate matter clouds (log-normal plots).

CRITICAL FACTORS IN DETERMINING ACCEPTABLE EXPOSURE

The nature of the health problems caused by inhalation of PM is influenced by a number of factors:

- ➢ Chemical and biological composition of the particles and stability of their nuclei (radioactivity)
- ➢ Crystalline, structural, and isotopic forms of the particles
- ➢ The shape of the particles
- ➢ The size of the particles
- ➢ Dose: concentration of particles in the work environment and exposure duration
- ➢ Preexisting health or genetic status of the workers
- ➢ Concurrent exposure to other toxic agents

Chemical and Biological Composition

The chemical composition is often a primary driver for the toxicity of a material. As reflected in their respective Threshold Limit Values (TLVs)® and OSHA Permissible Exposure Limits (PELs), beryllium is considered more hazardous than lead, which is more toxic than iron. Smoke from petroleum asphalt is considered less toxic than smoke from coal tar, because the latter typically has a much higher concentration of potentially carcinogenic polynuclear aromatic hydrocarbons.

Inhalation of free respirable crystalline silica may cause severe lung disease, silicosis. Rocks and soil that contain silicon dioxide chemically bound to other elements are termed silicates, which may have some toxicity of their own, but not generally on the order of free crystalline silica. A major exception is asbestos, which is a silicate with great potential for toxicity.

Exposure to *Bacillus anthracis* is potentially much more dangerous than exposure to *Bacillus subtilis,* even though they are closely related bacteria, because inhalation of *B. anthracis* can cause anthrax, a potentially fatal disease. Inhalation of *B. subtilis* is unlikely to cause any infection in healthy adults.

Inhaled radiological materials vary in toxicity for a number of reasons, but in most cases, a primary factor is the specific activity of the radioactive atom. Species with high specific activities emit a lot of ionizing radiation per unit of time and mass, and thus more rapidly affect tissue causing genetic and somatic cell damage. Also important is the type and energy of the radioactive particle (or photon) emitted when the atom decays.

Thus, plutonium, which has a high specific activity and releases very densely ionizing alpha particles, is considered to be one of the most radiotoxic atoms in existence. Natural uranium has a much lower specific activity and is correspondingly much less radiotoxic. A tritium compound, because of the very low energy beta particle it emits when it decays, is considered a minor hazard when inhaled in moderate amounts.

The type of molecule to which a radioactive atom is bound also affects its radiotoxicity. Soluble uranium compounds are much less carcinogenic than are insoluble or minimally soluble forms. The former, once deposited in the alveolar portion of the lungs, is rapidly removed by dissolution and often excreted promptly. Insoluble compounds of uranium, in contrast, can remain on the alveolar surface for a much longer period of time, all the while depositing ionizing energy into cells in the vicinity of the particle.

Crystalline, Structural, and Isotopic Nature

The chemical composition of various particles may be virtually identical, but other qualities of the molecules or atoms making up the particles may render them more or less toxic. The best-known example of this is silica (silicon dioxide). The most toxic form, "free crystalline silica" (quartz, cristobalite, and tridymite) are all well-defined, three-dimensional crystalline structures, not bound chemically to other elements. Inhalation of very fine particles of this free crystalline form of silicon dioxide causes "silicosis," a nodular, potentially progressive, and often-severe form of pneumoconiosis.

At the other extreme, rapidly cooled liquid silicon dioxide forms an amorphous (noncrystalline) structure called glass. This happens naturally in the formation of minerals such as pumice and obsidian, the latter displaying the appearance associated with manmade glass. Other examples of free silica that are not crystalline include diatomaceous earth, fumed silica, and silica gel. Although chemically identical to quartz and the other free crystalline silicas, amorphous silica lacks any repetitive crystalline structure. As a result of this difference, glass, natural or manmade, is of low toxicity and is generally regulated as only a "nuisance dust." In between these two extremes are other forms of silicon dioxide that have different levels of crystalline organization, and thus intermediate toxicity and Threshold Limit Values.®

Among organic PM, particularly smokes and soots, molecules with identical chemical compositions may have widely varying toxicity depending on the exact chemical

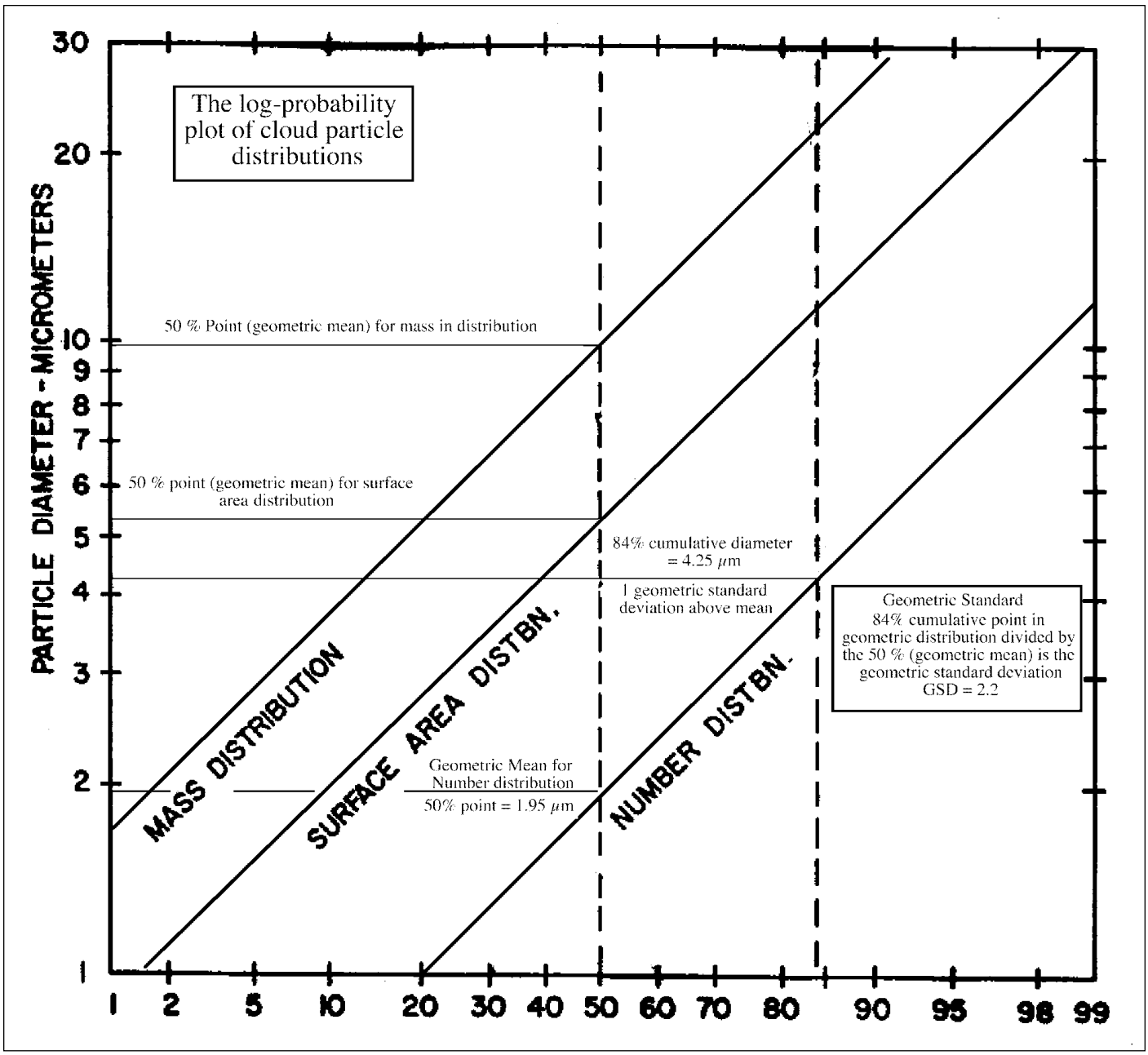

Figure 8–6. Cumulative log-probability plot of log-normally distributed particle cloud.

arrangement of the atoms which make up the organic molecule. For example, the polynuclear aromatic compound benzo-a-pyrene is a known mutagen and carcinogen. By slightly rearranging the atoms that shape benzo-a-pyrene, breaking the polynuclear structure, the material looses its mutagenic and carcinogenic potency.

Among organic molecules, even much less dramatic structural changes can vastly change the toxicity of a compound. For example, some organic pharmaceuticals have a chiral center, which may be either left or right handed. These pharmaceuticals are often effective (and toxic) because they contain or consist entirely of one isotopic *enantiomer,* either the left handed or right handed variety. The variation in structure is very subtle, but has a big impact on the drug effectiveness and potential for toxicity.

Some radioactive atoms have two or more distinct radioactive isotopes, varying structurally only in the number of neutrons in the nucleus of the atom. For example, naturally occurring uranium consists of three isotopes, U-238 (99.28%), U-234 (0.0006%), and U-235 (0.714%). The U-235 is the fissile isotope, capable of powering nuclear reactors and nuclear bombs. Because of its high specific activity, it is also the most radiotoxic isotope, with an additional significant contribution by U-234. Remove U-235, as is done to produce

fuel for reactors, and the remaining material, almost exclusively U-238, is primarily controlled as a kidney toxin, not a radiotoxic material. In contrast, U-235 enriched uranium is predominantly a radioactive hazard.

Shape of the Particles

By convention, there are six varieties of asbestos: chrysotile (a serpentinite mineral), amosite (in mineralogical terms, cummingtonite-grunerite), crocidolite (reibeckite), fibrous tremolite, fibrous anthophyllite, and fibrous actinolite (all of the latter members of the amphibole series of minerals). While all of these minerals vary in chemical composition, all of them share a general shape—they are fibrous. More specifically, they are "asbestiform," a type of fibrous habit that is much less common than the general term "fibrous." When shredded apart from their rock form, they exist in bundles of long, skinny fibers that are much longer than they are wide. As you further tear the bundles apart, you just get smaller and smaller bundles with the same general morphology. Ultimately, when all of the adhering particles are separated, the unit piece of an asbestos fiber, the *fibril,* retains the same general shape, long and narrow. Asbestos fibers are said to have a high *aspect ratio*. In mineralogical terms, asbestos always has an aspect ratio of at least 10:1; that is, it is 10 times longer than it is wide. Current OSHA analysis regulations define asbestos as having an aspect ratio of >3:1; the EPA defines it as >5:1. These regulatory aspect ratios are arbitrary and may introduce errors by being too low, especially the 3:1 OSHA/NIOSH ratio.

Each asbestiform mineral has a chemically identical non-asbestiform mineral. These non-fibrous analogues to asbestos do not present the same hazards of lung cancer, asbestosis, and mesothelioma as do the asbestiform varieties. Thus it is the shape of the asbestos fibers, which is actually determined by the crystalline structure (see above), that to a large extent defines their toxicity. Unfortunately, these non-asbestiform polymorphs (and other minerals) occur with asbestos in the earth's crust, and tend to form cleavage fragments called "pseudofibers" that meet the 3:1 aspect ratio criterion. By OSHA/NIOSH rules, they get counted as asbestos when they are not asbestos and generally do not pose the hazards presented by asbestos.

Because asbestos fibers can travel through the lung lengthwise, like an arrow, they can penetrate much deeper into the lung than a non-fibrous particle with a diameter equal to the length of the fiber. As a result, asbestos fibers many tens of micrometers long can make it to the alveolar region of the lungs, which would almost never happen with more regularly shaped particles of this size. Once deposited in this relatively undefended region of the lungs, it is believed that the fibers trigger an ineffective immune response by resident macrophages, which not only fail to remove the relatively insoluble fiber but die in the process, setting off a chain of immunological events, which results in scarring of the lungs and cancer.

In some arenas, the relative toxicity of the six forms of asbestos remains in debate. The TLVs® suggest differing exposure limits. Many mineralogists and some countries take the position that "white" asbestos, chrysotile, is less toxic than the brown or blue forms (amosite or crocidolite). This argument is based on some epidemiological and autopsy data, but also on the very different morphology of the serpentenite chrysotile from the amphibole species of asbestos. Airborne chrysotile fibers tend to be rather curly and twisted, less likely to travel through the air as an arrow and reach deeply into the lungs. Crocidolite and amosite, in contrast, form very straight fibers. A third argument in favor of establishing differing exposure limits between these families of minerals relies on the fact that chrysotile is more biosoluble than the other forms of asbestos, and thus will have less residence time in the alveoli to cause disease.

However, OSHA is resolute that all of the forms of asbestos present approximately the same hazard and should be treated identically. As a result, few industrial hygienists pay any attention to the TLVs for asbestos, and simply follow the OSHA regulations, which makes no differentiation among the asbestos types in terms of exposure limits.

Note that the term "asbestos" is a term of commerce, not science. There are other fibrous minerals, such as a fibrous zeolite called erionite and fibrous attapulgite, that may pose similar health hazards as asbestos. The costly lesson provided by the epidemic of asbestos-related disease has led industrial hygienists and toxicologists to worry about exposure to certain manmade fibers which share the characteristics of very small diameter, high aspect ratio, length, and low biological solubility.

Size of the Particles

The toxicity of some agents depends very strongly on the size of the individual particles to which employees are exposed. Obviously, as mentioned at the beginning of this chapter, to be of inhalation concern, a particle must not be too big, as it would not stay suspended in the air long enough to be inhaled, nor too small, as it then takes on the characteristics of a gas rather than a particle.

Industrial hygienists are not generally concerned with the actual diameter of a particle. Instead, they are concerned with the *equivalent aerodynamic diameter* (*EAD*) of a particle, sometimes called the *aerodynamic equivalent diameter (AED).*

This value predicts how a particle will behave when inhaled or challenged with a respirator or sampling filter. The aerodynamic equivalent diameter removes all of the aerodynamic variability induced by the shape of the particle and the density of the particle, and relates it to a spherical particle of unit density. Almost all of the exposure standards that require measurement of a size fraction of a dust actually require the measurement of the aerodynamic equivalent size of the dust rather than its physical size.

For moderately sized spherical particles (1–10 μm physical diameter), the AED can be pretty well estimated by the simple equation provided below.

Equation 2 (Spherical particles)

$$\text{AED} = \text{actual particle diameter} \times (\text{particle density})^{0.5}$$

- ➢ AED = Aerodynamic Equivalent Diameter in µm
- ➢ Actual particle diameter in µm
- ➢ Particle density in units of grams/centimeter^3

Thus, the AED is related to the actual diameter by multiplication with the square root of the particle density. In the example provided in Equation 2, it was assumed that the particle was spherical. With the exception of mists and very fresh fume and smoke, most PM is not spherical, and a correction must be made for the differential resistance to airflow induced by shape. This has been called the Dynamic Shape Factor, and has been introduced earlier in this chapter. The net AED for a non-spherical particle in the middle size range (1–10 µm) can be estimated in many cases by adding the dynamic shape factor to Equation 2.

Equation 3

$$\text{AED} = \begin{matrix}\text{particle}\\ \text{diameter}\end{matrix} \times \left(\begin{matrix}\text{particle}\\ \text{density}\end{matrix}\right)^{0.5} \times \begin{matrix}\text{dynamic}\\ \text{shape factor}\end{matrix}$$

- ➢ AED = Aerodynamic Equivalent Diameter in µm
- ➢ Actual particle diameter in µm
- ➢ Particle density in units of grams / centimeter^3
- ➢ Dynamic shape factor estimated from Table 8–D (unitless)

Thus, a talc particle, which tends to be in the shape of a flake, has a high *dynamic shape factor*, increasing drag as it moves through air, making it appear aerodynamically larger than it is physically. A fiber, which travels lengthwise as it moves in an aerosol and thus resembles an arrow, has a low dynamic shape factor, and moves in a manner more of a function of its diameter rather than its length. Typical dynamic shape factors for differently shaped particles are provided in Table 8–D.

The usefulness of these simple methods for determining AED starts to degrade progressively with very small and relatively large particles. Large particles tend to flow through the air with the creation of a lot of turbulence rather than laminarly, in effect making the particles AED smaller than it appears by calculation. Very small particles enter another flow regime, where they start to see the air as individual molecules rather than a continuum, and are subject to "slippage" between the molecules with reduced drag. Thus, they have an AED that is larger than these simple calculations would suggest. More sophisticated calculations, with consideration of Cunningham Slip Correction Factors and Reynolds' numbers can be made to partially correct for these effects, but such calculations are beyond the scope of this chapter.

In practice, aerodynamic equivalent diameter is usually determined empirically. When it is important to know the full size distribution of the dust, it is often sampled through a multi-stage separator, each stage collecting a certain aerodynamic "cut" or fraction of dust. Devices such as multi-stage cascade impactors can be used very effectively to show the count or mass distribution of a particle cloud. In one research project, the particle size distribution created by laser machining of a carbon composite versus that created by mechanical machining were compared by use of a cascade impactor. Simply by looking at the filters on the six stages in each impactor, it was obvious that mechanical machining produced a cloud dominated by large particles, whereas laser machining, which works mostly by a vaporization-condensation mechanism, produced only very fine particles.

The aerodynamic equivalent diameter of the particle is important because it determines where in the respiratory tract the particle is most likely to be deposited. As described in Chapter 2, the lung has different clearance mechanisms and particle residence times in different sections. In the nose, nasal turbinates, and throat (collectively the Head Airways Region or nasopharyngeal region) inhaled air moves rapidly through small diameter passageways with several sharp changes in direction. The larger particles, especially those with AEDs greater than 25 µm, are subject to removal by impaction in this area, and are either ejected through blowing the nose, or passed into the GI tract, completely avoiding the lungs. In the thoracic region of the lungs, also known as the tracheobronchial region (which includes the bronchi and larger bronchioles), the air slows down because of the greater cross section of flow, and impaction and inertial settling remove smaller particles, between 1 and 20 µm AED. Particles deposited in this region are usually reliably removed from the lung in a matter of hours by the mucociliary escalator, and thus have a limited residence time in the lung.

Finally, very small particles, those with AEDs significantly less than 10 µm, have an increasingly good chance of penetrating all the way to the terminal bronchioles and the alveolar sacs in the air exchange region of the lungs. In this region,

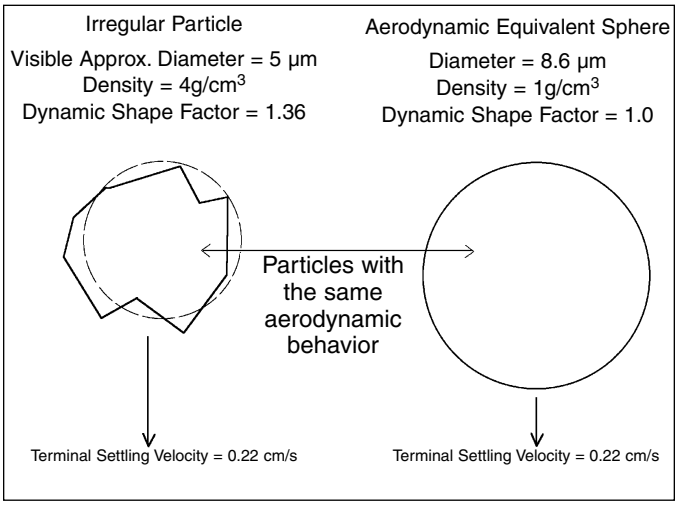

Figure 8–7. Real particle diameter and shape and aerodynamic equivalent diameter.

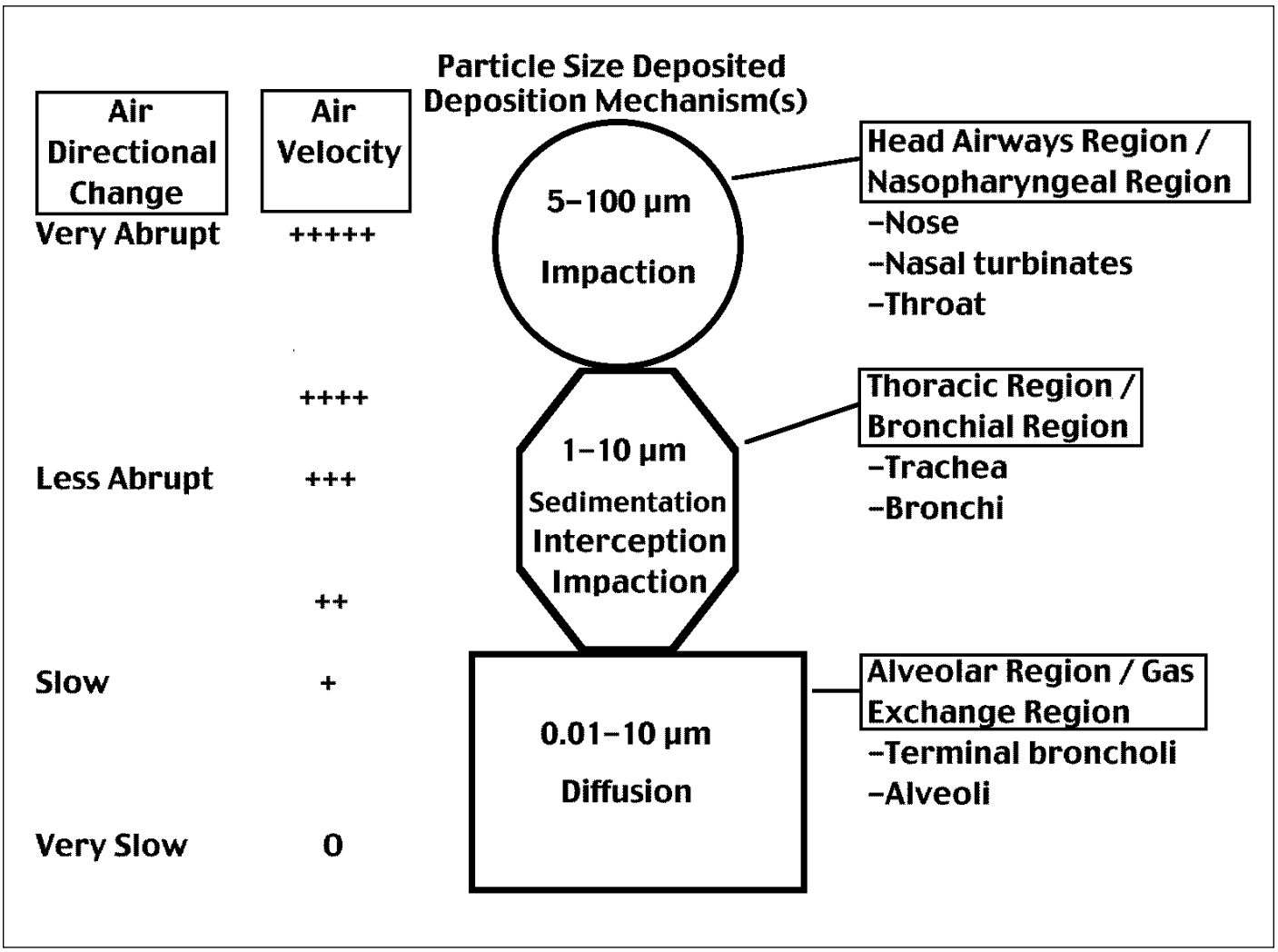

Figure 8–8. Respiratory tract particle deposition as a function of aerodynamic equivalent diameter (AED).

they may be deposited by diffusion (Brownian motion). Here, the only option for removing the particle is to dissolve it or let the macrophage physically transport it to a nearby lymph node. Particles deposited in the alveoli are attacked by resident macrophages, which attempt to engulf and dissolve them using a variety of digestive enzymes. Particles that are effectively moved from the alveoli by macrophages without dissolution pass into the lymphatic drainage where they may accumulate to cause illness or partially gain access to the systemic circulation. Particles that dissolve naturally are transported directly into the bloodstream by diffusion across the very thin capillaries that line the alveolar sacs. Particles that do not dissolve and are harmful to macrophages are often the serious pneumoconiosis-inducing particles, and they simply accumulate in the alveoli.

Real health consequences may arise when the particle is toxic and the macrophages are ineffective at removing it. One example of such a case has already been presented—asbestos. The macrophages do not destroy the asbestos particle, and in the process of trying, actually die and degrade, apparently triggering a cascade of biological responses that may be responsible for much of the fiber's toxicity. Quartz (the common form of free crystalline silica) is another highly insoluble compound, the toxicity of which is completely dependent on its penetration to the alveolar portion of the lungs. Quartz deposited in the nose, throat, bronchi, or larger bronchiole is completely non-toxic. Only when it is small enough to come to rest in the alveoli does it trigger the start of silicosis and cancer, probably by killing macrophages somewhat like asbestos. Many, but not all of the non-benign pneumoconiosis producing dusts act through this type of mechanism.

On the other hand, many particles demonstrate similar toxicity no matter where they are deposited in the respiratory tract. A soluble lead compound, for example, is likely to rapidly dissolve and enter the blood no matter where it is deposited in the respiratory tract. This is true of arsenic and many other soluble particulate matters. The poisoning occurs regardless of where the PM deposits in the respiratory tract.

Dose: Concentration of PM in the Work Environment and Exposure Duration

"All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy." This statement, written by Paracelsus (1493–1541) is an important starting point in understanding the concept of dose and dose-response relationships. At some dose, everything, including water, becomes toxic. Common table salt will kill half the people who consume four grams per kilogram of body weight in a short period of time. On the other extreme, botulism toxin will kill half of the people who consume 10 nanograms per kilogram, a toxicity range of 400 million.

Most of the pneumoconioses require many years of exposure for toxic effects to manifest themselves. The same is true of carcinogenic PM, such as polynuclear aromatic hydrocarbons and cadmium fume. Some metals, such as arsenic and lead, typically result in poisoning that occurs after exposure of at least several months. A few hours of heavy overexposure to some metal fumes from welding or cutting, such as zinc, can result in a transient illness known as metal fume fever.

Of course, all of these timeframes are affected by the concentration of the contaminant in the workplace air. Silicosis, a classic pneumoconiosis, can occur in a matter of months when the exposure level is very high. High exposure to cadmium fume can cause acute pulmonary edema, which can be fatal in days. At very high levels, lead toxicity may manifest itself in less than a week.

What is a safe level for exposure to a potentially toxic PM in the workplace? This depends on many factors. First we must consider the concentration of PM in the workplace air. In almost all cases, higher concentrations are more dangerous than lower concentrations. Industrial hygienists have an assortment of mandatory regulations and voluntary guidelines to follow to determine what is a "safe" exposure level. Federal OSHA Permissible Exposure Limits (PELs) regulate most U.S. exposure levels. PELs carry the force of law. Some of the larger states have developed their own (typically equal to or lower than federal OSHA) PELs for some toxic PMs.

The National Institute of Occupational Safety and Health (NIOSH) has developed a number of Recommended Exposure Limits (RELs), which are promulgated to guide OSHA in future rule making. Finally, the American Industrial Hygiene Association publishes voluntary guidelines called WEELs, "Workplace Exposure Evaluation Levels."

OSHA is very slow to adjust to new data and new views, and is subject to extreme political pressures. Thus, PELs, in particular, rarely change.

Many responsible employers also follow the guidelines established by the American Conference of Governmental Industrial Hygienists called Threshold Limit Values®, or TLVs®. These are updated yearly, and often provide more current values for controlling employee exposure.

Lacking a PEL, REL, WEEL, or TLV®, some manufacturers or employers will develop their own recommended exposure limits, based on toxicity testing or their handling experience.

Occupational exposure limits (OELs) for chemical compounds are defined against several different time bases. Most TLVs and PELs are defined as eight-hour time weighted average exposures. Many RELs are based on a 10-hour exposure period. Historically, the TLVs have also included Short Term Exposure Limits (STELs), which were a 15-minute average of exposure, but this concept has largely been dropped in recent years. Only a few compounds retain STEL limits. Another common limit is the "Ceiling" limit, abbreviated simply as "C," which is a concentration of the chemical agent which is usually intended as an absolute limit, a value never to be exceeded even for a short time.

OSHA retains as a historical artifact the concept of "Peak Above Ceiling," which is a limit that allows short periods of exposure above the ceiling value. The time basis for the peak above ceiling varies from agent to agent. Among PM, only beryllium and its compounds, chromic acid and chromates, and fluoride-containing dust are subject to the peak above ceiling limit. Finally, the OSHA standard for asbestos provides an "excursion" limit, which is a 30-minute average exposure.

For radioactive particles, the airborne limits are termed "Derived Air Concentrations" or DACs, which are published by the International Conference on Radiation Protection (ICRP). These figures are airborne limits that are back-calculated from the pre-established limit for radiation dose to the lungs and other tissues. Unlike chemical exposure limits, which are usually expressed as eight-hour average exposure limits, the DACs are year-long averages. Exposure slightly above a DAC on one or several days is not important if exposure is well below the DAC on the majority of workdays.

For many particulate matters, the level of exposure multiplied by the long-term duration of exposure (the *dose*) reveals the real measure of safety provided by the occupational exposure limit. For example, in diseases that are cumulative without a safe "threshold," as is generally thought to be true for asbestos-induced cancers, it is not the daily exposure that is important. It is the average exposure over the employee's career that establishes his or her residual risk of developing asbestos-related cancer. According to OSHA, exposure at the current limit of 0.1 fiber per cubic centimeter of air averaged over an 8-hour day for a working lifetime will increase an individual's risk of developing asbestos-related cancer by about 0.3–0.4 percent. Against the total likelihood of developing cancer over an individual's life of 22 percent, this residual risk is considered acceptable.

Other particles have only a short-term effect on the exposed individuals, not a cumulative effect. Where an occupational limit is set to control irritation, as in the case of sodium hydroxide dust or mist, if it is effective on one day, it should be equally effective on every day. Exposure at that level for many years is not likely to result in any long-term

disease. It is worth noting that exposure limits set to minimize irritation usually assume that the employee is regularly exposed to the irritating agent. Inexperienced or transient workers are often severely affected at levels that are below the ceiling or short-term exposure limit.

In between are chemicals for which toxicity is somewhat cumulative, but not linearly cumulative as assumed for many carcinogens. Lead is a good example. Everybody is exposed to lead every day in minute amounts through the air we breathe, the food we eat, and the water we drink. Yet because the dose is small, virtually nobody develops lead poisoning. This occurs because the lead is slowly but continuously eliminated from the body. An equilibrium concentration of lead in the body is achieved which is below the level necessary to cause disease. As the dose increases, the body's ability to keep up with the accumulation of lead lags, and the body burden of lead climbs. Assuming a constant dose, eventually the body will reach a new equilibrium of lead burden, which may exceed a safe level. At this point, signs and symptoms of lead poisoning appear.

Many occupational exposure limits carry poorly defined residual risks, and in the case of the TLVs®, the ACGIH states that the limits "refer to airborne concentrations…under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effects. Because of individual suceptibility…(some people) may be affected more seriously…by development of an occupational illness."

The environmental limits for exposure of the general population to PM are generally much lower than the occupational limits. For example, the limit for beryllium in the environment is 0.01 $\mu g/m^3$, 200 times less than the occupational exposure limit. This arises from a variety of considerations, including the potential of exposure to the sick, young, and elderly in the general population, 24 hour-a-day exposure, and a general attitude that residual risk rates for the public should be much lower than residual risk rates acceptable in the occupational setting.

Preexisting Health or Genetic Status of the Worker

Occupational exposure limits for particulate matter are generally set for "healthy workers." They do not, in most cases, take into account the variable susceptibility of individual employees because of preexisting health problems or genetic endowment. Many of the *expanded OSHA standards* do require some medical evaluation of workers before significant exposure to a specific PM (e.g., asbestos, lead, cadmium, and arsenic).

The ACGIH and the Centers for Disease Control and Prevention recommend blood lead levels much lower for pregnant or potentially pregnant women than for other women, not to protect them against lead health effects, but to protect the fetus from the teratogenic and fetotoxic effects of the mother's elevated blood lead level. In a comprehensive industrial hygiene program, all women who become pregnant or are trying to become pregnant would have their workplace evaluated for potential exposure to teratogenic or fetotoxic exposures, including radiation exposure when applicable. However, a court decision has made it clear that a woman cannot be forcibly discharged or even shifted from one job to another to protect her fetus, as long as her exposure and biological monitoring results fall below the minimum OSHA standards. It should also be noted that lead may have a variety of adverse effects on the male reproductive system as well, most notably on fertility and sperm function.

However, for the vast majority of PM hazards, there is no requirement to perform preexposure medical assessment of the workers to determine if they have conditions that might make it imprudent to be exposed to the PM in question. No generally applicable regulation requires prescreening for individuals who are to be exposed to beryllium, chromium, cobalt, barium, diesel exhaust, nickel, pentachlorophenol, thallium, or dozens of other occupational particles.

Concurrent Exposure to Other Toxic Agents

Often, exposure to particulate matter or other types of airborne hazardous materials do not occur in isolation. Rather, exposure occurs to more than one type of PM or PM plus gases, vapors or infectious agents. While in many cases these multiple exposures do not interact, in some cases they may interact additively or synergistically.

An example of a noninteractive concurrent exposure would be lead and asbestos. While they are both primarily occupational hazards as aerosols, their target organs, health effects, and pharmacokinetics are very different. Lead is primarily neurotoxic, even though it gains access to the body through the lungs. Asbestos is toxic mostly in the lungs, and causes lung diseases such as cancer and asbestosis. Lead is somewhat cumulatively toxic, but it has a threshold below which there is no risk of developing lead poisoning. Asbestos is usually assumed to be fully cumulatively toxic (especially the less soluble forms amosite and crocidolite) with no threshold. When both exposures are measured simultaneously, the results are treated independently, and if both exposures are below the appropriate limits, then the operation is in compliance.

Other exposures are known or assumed to be additive. For example, it is prudent to assume that co-exposure to any of the pneumoconiosis-producing dusts listed in Table 8-C would be additive, as they produce variably related conditions. Thallium and lead have very similar toxicological profiles, so again it would be appropriate to consider these concurrent exposures as additive. The more closely the particulate matter-related health effects are, the more appropriate it is to judge them to be additive. When both exposures are measured simultaneously, the TWA fractions of the respective exposure limits found for each agent are added together, and if the value exceeds 1.0, then an overexposure situation is assumed to exist.

Equation 4

$$\frac{\text{Measured exposure agent 1 (TWA)}}{\text{TLV*–TWA for agent 1}} + \frac{\text{Measured exposure agent 2 (TWA)}}{\text{TLV*–TWA for agent 2}}$$

* PEL, REL, or WEEL may be used instead of TLV®, as is most appropriate

An example of application of additive calculation for measured concurrent exposures to lead and a soluble thallium compound is provided below:

$$\frac{\text{Lead: Measured exposure is 0.03 mg/m}^3\text{ (TWA)}}{\text{PEL-TWA = 0.05 mg/m}^3} + \frac{\text{Thallium: Measured exposure is 0.05mg/m}^3\text{ (TWA)}}{\text{PEL-TWA = 0.10 mg/m}^3}$$

The sum of these is 1.1. As this exceeds 1.0, the measured worker is assumed to be overexposed to the additive metals (lead and thallium in this case). If taken separately, each metal would be below its corresponding PEL, and an overexposure would not exist. Note that this type of additive analysis can be conducted for three, four, or even more agents sampled at the same time. It may even include a mixture of PM, vapors and even physical agents. This is a determination which must be made on a case-by-case basis by an industrial hygienist.

Other PM exposures are synergistic. For reasons not totally clear, the health consequences of concurrent inhalation of cigarette smoke and asbestos exposure are much greater than the sum of the parts. Both attack the lung and both cause cancer, but when exposure occurs at the same time, there is a very large synergistic increase in the risk of developing lung cancer.

Lung infection and exposure to pneumoconiosis-producing dusts often seem to act synergistically. Silicosis predisposes workers to the development of active tuberculosis that progresses along with the pneumoconiosis and makes the pneumoconiosis much worse. Emphysema often adds to the problem when there is concurrent silicosis and tuberculosis. While some cases of silicotuberculosis may result from activation of latent disease, it appears that other cases arise due to concurrent exposure to silica and *Mycobacterium tuberculosis.*

Concurrent pneumoconiosis from kaolin and infection with tuberculosis causes synergistic fibrosis. The same thing can happen with asbestosis. However, in the latter two cases, unlike silicosis, the presence of these other pneumoconioses does not seem to actually enhance susceptibility to tuberculosis. Concurrent proliferation of *Candida albicans* (a normally present but quiescent fungal infection in humans) and asbestosis appears to be synergistic. Some types of co-infection cause coal miners' pneumoconiosis to change from a fairly benign disease to a very serious and progressive illness.

A number of co-infections probably are promoted by pneumoconiosis-producing dusts or act synergistically to cause more severe forms of the pneumoconiosis.

There is no routine mathematical way to account for synergistic effects.

BIOLOGICAL REACTIONS

There is a wide range of biological responses to deposited particulate material. Some of these are described below.

- ➢ Acute sensory irritation of the upper and middle air passageways, including a burning sensation in the upper airways and coughing from laryngeal stimulation. Continued exposure may result in bronchioconstriction.
- ➢ Pulmonary irritants stimulate sensory receptors in the lungs and induce rapid shallow breathing, dyspnea, and breathlessness. If the exposure is high enough or prolonged, more severe responses including airway constriction and pulmonary edema may occur. Secondary infection may complicate severe cases.
- ➢ Lung edema without sensory irritation. For example, cadmium oxide can be fatal by this mechanism in high doses.
- ➢ Some irritants can cause acute or chronic bronchitis, which is the overproduction of mucus, and lead to cough and dyspnea (e.g., vanadium compounds, endotoxin).
- ➢ Allergic sensitization resulting in extrinsic allergic alveolitis or asthma arises from many exposures, including isocyanates, certain wood dusts, complex biomolecules, mite feces, pollen, cotton bract (byssinosis), mold spores [mushroom pickers lung, maple bark strippers lung, [cheese washers lung], thermophilic actinomycetes [farmers lung], dried sugar cane (bagassosis).
- ➢ Fibrosis, which is a type of scarring of the lung tissue, results in loss of flexibility, difficulty breathing, and in severe cases, damage to the right side of the heart as it tries to compensate for reduced blood oxygenation. Many of the pneumoconioses result in fibrosis. There are many different types of fibrosis, some localized and some very diffuse, as discussed previously. They may present a restrictive or obstructive pulmonary function profile, or a mixture of the two.
- ➢ Emphysema, which results in obstructive lung function. Particulate matter examples include cadmium oxide and cigarette smoke. Many gases result in emphysema as well.
- ➢ Systemic toxicity resulting from dissolution of inhaled particles in the lung or in the digestive tract after being removed from the upper and middle airways. Examples include lead, arsenic, thallium, pentachlorophenol, fluoride salts, manganese, soluble radioactive compounds, and toxic fungal spores.
- ➢ Lymphatic toxicity from particles physically moved to the lymphatic system from the alveoli by macrophages. Insoluble radioactive particles may cause this type of damage.
- ➢ Oncogenesis, the initiation or promotion of cancer. Examples are many, and include arsenic, asbestos, beryllium, chromium +VI compounds, coke oven emissions, nickel, free crystalline silica, cigarette smoke, and at least certain hard wood dusts.
- ➢ Infection (e.g., *Coccidioides immitis, Mycobacterium tuberculosis, Legionella* species, *Hanta virus*).

➢ Metal fume fever, which typically resembles flu, and results from overexposure to fresh metal particles, especially fume, of zinc, magnesium, and copper or a number of other metals or their corresponding oxides. It tends to occur in employees who have not been recently exposed to these fumes. Symptoms start four to 12 hours after inhalation, and are self-limiting in almost all cases.

Note that some types of particles can cause a range of lung toxicity depending on the specific compound containing the active element, the particle size, and the exposure rate. Thus, arsenic can cause pulmonary edema, systemic poisoning, or lung cancer. Second-hand cigarette smoke can cause emphysema, bronchitis, or lung cancer. Asbestos can cause asbestosis or lung cancer.

SAMPLING AND ANALYSIS OF PARTICULATE MATTER

Most samples taken to assess exposure to PM are air samples. Most often, the particles are removed from the aerosol by filtration, impaction, electrostatic attraction, or wetting, with subsequent analysis of the collected particles in a laboratory by chemical or microscopic methods. Although less common than when sampling for gases and vapors, direct-reading real time instruments are also used to measure airborne PM as well, commonly by detecting their scattering of light.

However, other types of particle sampling are also common in industrial hygiene. Surface sampling in areas where hazardous aerosols are present is a fairly common tool, recognized by OSHA as industrial hygiene sampling data, with the same rules about record retention as apply to air samples. Occasionally PM from clothing or skin surfaces will be collected as an indication of dermal exposure. This method is commonly used in research on particles that pose substantial transcutaneous hazards, such as some pesticides.

Bioassays exist for many particulates that provide an indication of actual absorbed dose or biological changes resulting from absorbed dose. This may be done by analysis of urine or blood. The American Conference of Governmental Industrial Hygienists has established a number of recommended bioassays for PM, mostly for metals.

It is actually rather common to use two or more of these sampling methods to monitor or evaluate the exposure of a particular individual. Personal air samples are an excellent indicator of PM exposure on that shift, biological monitoring may provide a measure of exposure across many shifts, and surface sampling provides information on the effectiveness of engineering and administrative controls over the longer term.

Sampling for Particulate Matter

Air sampling for particulate matter is a fundamental industrial hygiene activity. The vast majority of occupational exposure limits are based on the results of air sampling. Air sampling can be integrated over various periods of time, ranging from samples which last days or weeks for environmental measurements or point source release of radioactive particulate matters, to direct-reading real time sampling intended to measure ceiling or peak exposures. For occupational exposure purposes, the eight-hour time-weighted average is the most commonly measured value.

Integrated industrial hygiene air samples are most typically collected onto filters placed in the *breathing zone* of the worker (within ~12 inches of their nose and mouth), with air drawn through the filter at a rate of 0.5 to 3 liters per minute. This way, the filter goes where the worker goes, and collects particles based on the airborne concentration of PM wherever that employee moves over an eight-hour shift. Although common in the past, now a liquid impinger is only occasionally used to collect particles in modern industrial hygiene practice. Before the 1960s, asbestos and coal dust were usually collected in impingers, but now they are collected on filters.

Less common now, although a standard in the past, is the *general area* sample, typically taken with a plug-in pump. One version of this type of instrument is operated by a 1/5–1/3 horsepower vacuum pump, and draws air through a 25 to 47 millimeter diameter filter at rates varying from a fraction of a cubic foot per minute (CFM) to a couple of CFM. This is sometimes casually referred to as a "high-volume" (or simply hi-vol.) sampler. Another version of an area sampler, a true high-volume sampler, uses a vacuum cleaner motor to draw air through a filter as large as 8 x 10 inches at a rate of 20 to hundreds of CFM. Sampling devices that collect specific size fractions of PM are used extensively in the environmental or community setting. Samplers such as the PM 10 collect particles at 50 percent efficiency with AEDs less than 10 μm, and the PM 2.5 and PM 1.0 act similarly for those smaller particles.

General area sampling is used extensively in specific settings, asbestos abatement in particular. Typically, samplers are set up around the perimeter of an isolated asbestos dust containment area as a means of verifying the adequacy of the controls. With phase contrast microscopy (the primary OSHA analytical method for counting asbestos fibers) the samples, which may be collected in as little as one to two hours and analyzed on site in a matter of 30 minutes, provide rapid feedback on the effectiveness of the dust containment. Following an asbestos abatement action in a full containment, it is typical to take one or more *clearance samples* as a means of verifying the complete decontamination of the air and surfaces in the contained area. These area samples, collected on 25 or 37 mm filters at 10 to 16 liters per minute (depending on the analytical procedure), are usually taken using "aggressive techniques," traditionally using a leaf blower and fans to stir up any settled or residual dust. Thus the result(s), whether analyzed by phase contrast or by transmission electron microscopy are a hybrid sample, partially reflecting what was actually in the air, and partially counting what was on the surface but capable of being made airborne.

Figure 8–9. Tools of industrial hygiene.

Microbiological Sampling

General area samples are still commonly used for sampling airborne bacteria and fungal spores. Traditionally, samples were collected by impingement in a liquid with a device called the "all glass impinger-30," with subsequent dilution and plating out and culturing of the suspension or direct optical counting of the collected bioparticles. While this method is still in use, especially for bacteria, in the 1970s and 1980s, it became more common to collect viable bacteria and fungal spores on a petri plate filled with a growth medium loaded into a modified single stage "Anderson" impactor. Buoyed by the publication of an ACGIH guideline for using this method in 1986, the collection of viable microorganisms by drawing air through a 400-hole sixth stage of a multistage cascade impactor became the norm. When air from each hole hits the growth medium, a viable bacterial or fungal spore can impact and eventually grow.

Originally, these samplers were built by cannibalizing multistage cascade impactors. In time, appropriate single stage impactors became available commercially. Eventually, NIOSH developed written sampling methods for these impactors (NIOSH 0800 and 0801). Standard collection agars have come to be tryptic soy and tryptic soy with five percent sheep blood for bacteria (sometimes with mold inhibiting additives), and with malt extract, rose bengal, potato dextrose, dichloran glycerol, Czepak Cellulose, and corn meal for molds. Almost all of the single-stage, 400-hole agar impactors are designed to operate at 1 CFM (28.3 LPM). Smaller personal versions of single stage impactors are commercially available.

Other viable spore collection devices that acted similarly, such as the RCS sampler, were marketed successfully, although in its original version, the RCS unit was inefficient for smaller bacteria and spores.

Once cultured under specified conditions, the number of colonies was counted and the total airborne loading of viable bacteria or fungal spores was determined, in units of *total colony forming units per cubic meter* (CFU/m^3).

In time, it became apparent that live culture/total colony count method had several limitations, including its relative difficulty of use, lack of typing of the fungus or bacteria, and the varying presence of potentially large numbers of airborne microorganisms, which were dead and would not grow once collected, but retained their potential allergenic or toxigenic properties.

It is still common for aeromicrobiological sampling to be performed by area sampling rather than personal sampling. While the viable sampling methods are still in common use with some modification, methods of collecting all cells and spores whether viable or not, were developed, This included the Burkhart Spore Trap and most recently, the Air-O-Cell cassette. The cassette, usable with any pump capable of providing the required 15 liters of air per minute flow rate, impacts particles onto a sticky surface; the particles are then analyzed optically by a trained microbiologist to determine not only the number of organisms, but the genus and in some cases the species of the organisms.

It is quite unusual for an industrial hygienist to be asked to sample for infectious airborne bacteria, fungal spores or viruses, primarily because it is difficult to culture captured organisms, and the sensitivity of the methods is too low to detect meaningful levels of infectious agents. For example, soilborne spores of *Coccidioides immitis* when inhaled can lead to coccidiomycosis, a potentially severe lung infection, but air sampling is almost impossible, leading to false negative results. *Legionella,* the bacteria responsible for the outbreak of lung disease among the Legionnaires in 1978 as well as Pontiac fever is often sampled in bulk water sources such as cooling tower water, but almost never in the air. Tuberculosis is clearly transmissible person to person. A standard sampling and analysis protocol requires that the collected and cultured organisms then be inoculated into sensitive animals like guinea pigs to demonstrate infectivity. Anthrax and Q fever are common bacterial diseases transmitted by the air from animals to people (potentially over miles in the case of anthrax), and while there have been instances where these have been sampled by cascade impactor or impinger, it is rather unusual. Q fever has been sampled in animal rendering plants for occupational purposes. Some viruses, including measles, have been sampled as part of larger mists or dusts in hospitals and other health care settings but this is not routinely done by industrial hygienists.

In some industries and many indoor air quality evaluations, it is common to sample for "endotoxin," which is a family of lipopolysaccharides in the outer membrane of gram-negative bacteria. Inhalation of endotoxin can induce flu-like or asthma-like symptoms or more serious lung illnesses. Oddly, while these molecules may cause short and intermediate term adverse health effects, they may also stimulate the immune system so as to render the exposed employee relatively resistant to some types of cancer.

Endotoxin can occur in bacteria growing in humidifier water in buildings, and in cotton dust, agricultural dusts, and machining oils. It is often collected on polycarbonate capillary pore filters or in impingers.

Radon and Radon Progeny

Radon is one of the "noble gases," which generally refuse to react with other compounds and therefore are almost always found as gases. Radon is a naturally occurring gas that is usually formed by the radioactive decay of uranium. Even though the gas is radioactive, it is not usually an occupational hazard, as it is not significantly absorbed as a gas when in contact with surface of the lungs.

However, as radon radioactively decays by the release of an alpha particle (nucleus of a helium atom), it turns first into radioactive polonium, then through several other radioactive isotopes including two forms of radioactive lead, and finally into Lead 206, which is not radioactive and makes no pretense of nobility. These intermediate radioactive materials are not gases, are charged, and rapidly attach themselves to oppositely charged particles in the air. Very quickly, a radioactive particle is formed, and when inhaled, is subject to lung deposition with subsequent radioactive decay through a series of other radioactive forms. These particulate matter decay products have traditionally been called *radon daughters,* or more recently, *radon progeny.*

Deposition of radioactive particles in the lungs presents the risk of inducing respiratory tract cancer. Airborne radon tends to accumulate where uranium is stored or inside poorly ventilated basements. Indeed, radon accumulation from naturally occurring uranium in the soil is common inside houses and some workplaces where the soil uranium concentration and soil gas permeability is high. Many thousands of homes across the United States have radon levels above the guidance level set by the EPA of four picocuries per liter. However, the classic workforce subject to radon daughter exposure is mining. This is an obvious hazard in uranium mining (or processing or handling), but also occurs with some regularity in other types of mining where uranium is present in fairly high concentrations. Excess lung cancer has been demonstrated in mines where radon daughters are present at elevated levels, although oddly enough, to date excess cancer rates have not been associated with living in houses with equally high levels of radon daughters. It is likely that some additive or synergistic effect is occurring among miners.

Most radon or radon daughter sampling is done using area methods. While radon daughters are sometimes measured directly by collection on a filter and counting under a gas proportional or thin-window solid state scintillation counter, in many settings the radon itself is collected by diffusion onto treated, activated charcoal-containing sorption media. The charcoal is then analyzed by a method such as liquid scintillation counting to directly determine the radon content. While the radon concentration itself is of no importance, in many settings the radon is in equilibrium with the many radon daughters, and the hazard posed by the radon daughters can be inferred from the radon levels. Control the radon level, and effectively the radon daughters are controlled.

Diesel Exhaust

Diesel exhaust has been shown to be carcinogenic, as it contains high concentrations of oncogenic polynuclear hydrocarbons. The particles are very small and thus respirable.

Table 8–E. *Filter Particulate Matter Collection Media Used in Industrial Hygiene*

Plain Filters	**Diameters / Pore sizes**	**Uses**
Cellulose	37 mm /undefined	Radioactive particles
Mixed cellulose ester	25–47 mm / 0.45–1.2 µm	Welding fume, asbestos, lead, cadmium, beryllium, sodium hydroxide mist
PVC	25–47 mm / 0.8–5.0 µm	Gravimetric dust, chromium paint overspray, silica, aluminum oxide, cotton dust
Glass fiber	13–47 mm / 1.0 µm	PCB mist, carbaryl, chloramphenicol
Polycarbonate	25–47 mm / 0.4–0.8 µm	Asbestos for TEM
Silver membrane	25–37 mm / 0.45–0.8 µm	Coke oven emissions
Teflon	13–47 mm / 0.45–5.0 µm	Assorted polynuclear aromatic hydrocarbons (as in soot, diesel exhaust, petroleum asphalt fumes, cigarette smoke)
Nylon	25–37 mm, 1.0 µm pore size	
Quartz	37–47 mm / undefined	Diesel particles
Coated Filters	**Characteristics**	**Examples**
Glass fiber/sulfuric acid	Stabilized MOCA on filter	4-amino biphenyl
		4,4-methylene dianiline
		MOCA
Mixed cellulose ester/ sodium carbonate		Arsenic trioxide
Glass fiber/1-(2-pyridyl) piperazine	Chemical reaction with isocyanates to stabilize them on filter	Toluene, diisocyanates, methylene, diphenylisocyanate, 1 and 2 naphthylamine
Unusual Filters	**Characteristics**	**Examples**
OSHA versatile sampler	Combination vapor/particle collectors. Filter portion may be glass or quartz fibers	Pesticides, organo-tin compounds, TNT, DNT, phthalate esters, glycols
Polyurethane foam (PUF) tubes	Very thick plugs of foam are used to collect mist phase of mixed vapor/mist	Pesticides, PCBs, dioxins, polynuclear aromatic hydrocarbons (area samplers)

Much attention is being paid to the levels of diesel exhaust and similar high PNA particulate matter (asphalt fumes, environmental tobacco smoke) in the field of air pollution. Concern for these agents is to starting to appear more often in the industrial hygiene literature. NIOSH has developed an analytical method, 5040, meant to sample for total elemental carbon as a simple surrogate for diesel exhaust carcinogenic compounds. The analysis involves thermal optical methods that are fairly specific for carbon. The diesel particulate matter standard and equipment are intended to be used in the effluent line, and thus may be exposed to high heat levels. The filter of choice is the 37-mm, heat-treated quartz fiber filter, and respirable sampling using a cyclone is recommended. The Mine Safety and Health Administration has also developed a set of specifications for sampling diesel particulate matter in mining environments, but the availability of sampling devices to meet these criteria is currently very limited. Many methods are available to sample and analyze specific polynuclear aromatic hydrocarbons (PAHs), the presumed primary carcinogens in these partial combustion products. A practice that may come into common acceptance is to analyze for 15 of the predominant PAHs in diesel exhaust and sum these. The ACGIH has already proposed this type of standard for oil mist.

Size-Selective Particle Sampling and Analysis

There is growing emphasis in industrial hygiene to use particle size-selective sampling to better characterize the level of exposure to relevant dust rather than total dust.

This can be done in a couple of ways. The oldest size-selective analysis, which is still used, observes each particle microscopically and counts only those that meet the preestablished size criterion. Starting in the 1920s, dust was collected by hand operated pumps into 1 liter *water-filled impingers*. Under the microscope, only particles with an approximate diameter of less than 10 µm were counted, in an effort to estimate the size fraction that was thought to be a toxicologically significant respirable fraction.

Asbestos remains as one of the few PMs that is routinely analyzed by size-selective microscopic counting. Optical (or electron) microscopy visualizes the collected fibers. The actual size of each particle determines if it gets measured. Under OSHA and the asbestos "A" NIOSH optical counting rules, the fiber must be >5 µm long and have an aspect ratio of at least 3:1. Under the more recent EPA electron microscope counting rules the fibers must be >0.5 µm long and meet a 5:1 aspect ratio. Neither of these procedures establishes an independent fiber diameter counting rule.

Most of the optical asbestos (and other fiber) methods used historically and around the world selected 5 μm in length as the minimum countable fiber. When the membrane filter collection method was formally adopted by the U.S. Public Health Service in 1969, the optical microscopy size-selective counting rules (which were subsequently adopted by OSHA and the ACGIH) were based on limiting the time burden on the analyst. Counting all of the short fibers would be highly time consuming. This is how the 5-μm limit was set, despite other published accounts suggesting prescient toxicology was taken into account or some other scientific logic drove this decision. As it turns out, recent toxicological evidence does suggest that fibers shorter that 5 μm do have reduced toxicity.

Fibrous glass or other manmade vitreous fibers (MMVF) have a mass per volume standard under OSHA—they are treated as a nuisance dust and evaluated gravimetrically. However, more recently, the ACGIH has established a TLV® for fibrous glass in units of fibers per cubic meter of air, like asbestos (they still retain their gravimetric standard, however).

The usual analytical procedure for MMVF is the NIOSH 7400 method, using the "A" counting rules, as for asbestos. However, this makes it necessary to count "OSHA fibers" no matter how large in diameter. Many fibrous glass products tend to be composed mainly of fibers that are quite large in diameter, and thus will be nonrespirable. Recall, a fiber tends to flow in an aerosol with an AED equal to about three times its actual width, which in the case of a 3-μm wide fiber is 9 μm. Thus, many nonrespirable and presumably nonharmful fibers are counted. This can result in what is probably an unreasonable overcount. Use of the "B" counting rules under the NIOSH 7400 method or the AIA RTM 1 method allows the discounting of fibers larger than 3-μm in diameter, thus avoiding overcounting associated with very large-diameter and likely fairly harmless particles.

Other size-selective sampling and analytical methods use some sort of mechanical separator in front of the collection medium to limit the size of the collected particles to a specified effective aerodynamic diameter. Over the years, several types of selective separators have been used. After collection of the appropriate size fraction, analysis can then proceed by chemical, gravimetric, or other means.

The best known example is the use of a separator to limit collection to the respirable mass fraction. In 1952, the British Medical Research Council first proposed exactly what defined the "respirable mass fraction," intended for use with pneumoconiosis producing dusts. This method was an area sampling method and used a *horizontal elutriator* to remove the nonrespirable fraction. The U.S. Atomic Energy Commission (AEC) in 1961 followed this with a modified curve for use in nuclear facilities. By 1968, the ACGIH developed its own respirable dust curve, very similar to the one used by the AEC, and specified its use for free crystalline silica-containing dust. Size selectivity was to be provided by a cyclone, a 10-mm nylon Dorr-Oliver cyclone for personal samples, and a 2-in. cyclone for high volume area samples. As it turned out, when the Occupational Safety and Health Act was passed in the United States in 1970, and OSHA was assembled a year later, it adopted verbatim the ACGIH TLVs®, including the respirable dust curve, as it applied to free crystalline silica-containing dust.

Table 8–F. ***The ACGIH/ISO/CEN/NIOSH Respirable Particulate Mass (RPM) Criteria***

AED	% RPM*
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

* This table indicates the percentage of particles of a given aerodynamic equivalent diameter (AED) in a polydisperse particle cloud that should pass through the size-selective sampler and be collected on the sample medium. Larger particles are not collected for analysis.

In the 1991 and 1992 respectively, the ISO (International Organization for Standardization) and CEN (the European Standardization Committee) had settled on a slightly modified respirable dust curve, which in 1993 was adopted by the ACGIH. NIOSH joined in the consensus at the same time. At this time, the ACGIH/ISO/CEN/NIOSH respirable dust curves are the same (Table 8–F).

The biggest change in this curve from the one adopted by OSHA in 1971 was the slight shifting of the 50 percent cut point from 3.5 μm to 4.0 μm. In theory, the new curve is more conservative, collecting a larger fraction of dust as respirable than the older curve. In practice, this small shift makes no practical difference, as both OSHA and the ACGIH recommend the continued use of the 10 mm Dorr-Oliver cyclone operated at 1.7 liters per minute, as established many years before. The resulting separation function is adequate for either curve.

Other respirable dust cyclonic separators are available as well. One company has long sold an aluminum cyclone that was originally designed to meet the old BMRC curve at 1.9 liters of air per minute. However, when operated at 2.5 liters of air per minute, it produces a respirable curve which very closely resembles the current ACGIH/ISO/CEN/NIOSH curve adopted in 1993. A slightly faster flow rate is recommended to better match the OSHA curve. Because it is composed of conductive metal, it is not subject to the disruptive effect of localized charge accumulation seen in nonconductive nylon cyclones. Conductive plastic respirable PM mass separators are also available which are advertised to reduce some of the other sources of bias inherent in the traditional Dorr-Oliver cyclone. These cyclones operate at 2.75 liters a minute to effect the respirable dust curve.

Table 8–G. ***Some TLVs® with Respirable Particulate Mass (RPM) Standards***

Particulate Matter	*TLV RPM (mg/m^3)*	*Comments*
Cadmium	0.002	RPM TLV, but not part of OSHA standard
Coal Dust (Anthracite)	0.4	Under OSHA, limit is: $\frac{2.4\ mg/m^3}{\%\ SiO_2 + 2}$
(Bituminous)	0.9	where quartz is <5%, otherwise use OSHA quartz formula
Diquat Dibromide	0.1	An herbicide, also has nonrespirable TLV
Graphite	2.0	All forms except fibers
Kaolin	2.0	Under OSHA, standard still only exists in mppcf units.
Mica	3.0	Under OSHA, standard still only exists in mppcf units
Paraquat	0.1	A pesticide, also nonrespirable TLV
Particulates not otherwise classified (PNOC)	3.0	Under OSHA, 5 mg/m^3
Silica:		
Free crystalline (quartz, tridymite, cristobalite)	0.05	In Federal OSHA, the quartz standard is given by:
Tripoli	0.1	$\frac{10\ mg/m^3\ (total\ respirable\ dust)}{\%\ SiO_2 + 2}$
Fume	2.0	
Fused	0.1	which is equal to essentially 0.1 mg/m^3 for pure quartz. Tridymite and cristobalite limits are given as 1/2 the quartz standard. Limits for amorphous forms are given by:
Diatomaceous earth	3.0	$\frac{80\ mg/m^3\ (total\ respirable\ dust)}{\%\ SiO_2}$
Soap Stone	3.0	Also nonrespirable TLV
Talc	2.0	Not containing asbestos. Under OSHA, standard still only exists in mppcf units.

Table 8–G lists a number of types of particulate matter for which the ACGIH has established respirable particulate mass standards. Some of the same chemicals with respirable TLVs® also have nonrespirable particulate mass standards.

The ACGIH has also established a PM subfraction called "Thoracic Particulate Mass" (TPM). TPM includes particles smaller than about 25 µm in AED, and represents those particles that make it past the head airways region and are available for deposition in either the tracheobronchial or alveolar regions. See Table 8–H. At this time, no TLVs are assigned to the Thoracic Particle Mass fraction. However, cotton dust and coke oven emissions have been suggested as possible candidates for TPM standards.

The ACGIH has also established an "Inhalable Particle Mass" (IPM) criterion. It is slowly moving away from traditional "total dust" collection, which is poorly defined and subject to a number of errors, toward the IPM criterion. (See Table 8–I.)

As an improved version of "total dust" sampling, this procedure is applicable for particles that can cause adverse health effects regardless of where they deposit in the respiratory tract. Formally recognizing the general belief that particles larger than 100 µm are not inhalable, the acceptance of the curve is undefined above 100 µm AED.

Special sampling devices are sold to implement the IPM sampling procedures, just as cyclones are sold to implement the respirable particle mass criteria. A few of the chemicals already assigned to inspirable particulate matter TLVs® include:

➢ Diquat
➢ Grain dust

Table 8–H. ***Thoracic Particulate Mass****

AED (µm)	% TPM*
0	100
2	94
4	89
6	80.5
8	67
10	50
12	35
14	23
16	15
18	9.5
20	6
25	2

* This table indicates the percentage of particles of an aerodynamic equivalent diameter (AED) in a polydisperse particle cloud that should be passed through the thoracic particle mass sampler and collected on the sample medium. Larger particles are not collected for analysis.

Table 8–I. ***Inhalable Particulate Mass (IPM)****

AED (μm)	% IPM*
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5
50	52.5
100	50

* Table 8-I indicates the percentage of particles of a given aerodynamic equivalent diameter (AED) in a polydisperse particle cloud that should pass through the inhalable particulate mass selective sampler and be collected on the sample medium. Larger particles are not collected for analysis.

- ➢ PNOCs
- ➢ Diatomaceous earth
- ➢ Soapstone
- ➢ Glass fibers
- ➢ Nickel, all forms

Inhalable mass samplers are often handled differently from typical "total dust" sample cassettes. In one common protocol developed by the Institute of Occupational Medicine in Scotland, a 25-mm filter is used inside a special holder. It is operated at 2.0 L/min to simulate the inhalable mass criteria. The cassette and filter are weighted pre- and post-sampling as a unit, reducing any loss of particles on the interior walls of the cassette, sometimes a severe problem when sampling for total dust with nonconductive polycarbonate cassettes. Also, this prevents the loss of any larger particles that might fall off the filter when it is removed for analysis using more traditional techniques.

There is one other significant size-selective separator still used in industrial hygiene. It is unique to the measurement of lint-free dust from primary cotton operations. Dust is sampled on a filter for gravimetric analysis, but first it must be passed through a vertical elutriator designed to provide a 50-percent acceptance size of 15 μm AED. This device is an area sampler only and cannot be used for personal samples. The interested reader is referred to the Transactions of the National Conference on Cotton Dust, page 33, JR Lynch, May 2, 1970.

For environmental PM sampling, particles size selectors with 10, 2.5, and 1 μm AED 50 percent cut points are used. These devices are not normally used in the occupational environment, although personal separators for PM 2.5 and 10 are commercially available, mostly for use in community air pollution work.

Dual-Phase Monitoring

On occasion, it is necessary to make a decision to sample either the particle phase of a mixed vapor/particle agent or the vapor phase. For example, when sampling with chemically treated filters for certain isocyanates in paint mist, only the particles will be collected and the vapor will be undetected. Another sample can be taken in a liquid filled impinger and almost all of the vapor and mist will be collected, with the possible exception of the very smallest mist, which can sometimes penetrate impingers.

Polychlorinated biphenyls (PCBs) are another agent which can expose employees to either a mist (if agitated or condensed) or vapor (if heated). NIOSH has a method that specifically addresses this by using a 13-mm glass fiber filter for mist, inline with an appropriate vapor sorbent tube.

Oil mist is usually collected on a filter, as in the NIOSH 5026 method. Depending on the vapor pressure of the oil, mass can be lost after collection by evaporation. A method that allows the evaporating oil to be adsorbed onto a collection tube after the filter would be desirable for high vapor pressure oils.

Isokinetic Sampling

Sometimes, it is necessary to sample PM in a moving airstream, such as after a HEPA filter bank ventilating a nuclear reactor. This introduces new aerodynamic problems into the sampling procedure that must be accounted for in order to obtain a valid sample of the PM in the airstream.

After the air has flowed through a HEPA filter, it is common to place a sampling tube in the duct, perpendicular to the air flow, to draw the air and deliver the particulate matter to a filter outside of the ventilation system. In some cases this might be a very sophisticated multiport air intake, designed specifically for that duct or stack. In other cases, it is a single tube, often of copper.

There are two critical factors to consider when performing the type of sampling described above. First, the airflow in the sampling line must be isokinetic with the airflow in the duct or stack. That is, the velocity of the air in the duct must be the same as the velocity of air in the sampling tube. If the sample velocity is less than the duct velocity, it will tend to result in overestimation of the particle mass in the ductwork. On the contrary, if the airflow in the sampling tube exceeds the airflow in the duct, it will tend to cause underestimation of the particle concentration. The effect of nonisokinetic sampling in a duct or stack can be quite severe. These effects occur primarily with the larger particles, due to inertial forces, as shown diagrammatically in Figure 8–10. Errors start to show up at particle AEDs of 3 μm, and become increasingly severe above 6 μm.

The other potential problem sampling in ducts and stacks is the use of a sampling tube with sharp bends. The sampling tube must face straight into the airflow, and it must curve slowly to achieve exit from the duct. Any sharp bends will cause particle accumulation at the bend by inertial impaction, which will cause the particles not to reach the filter and thus underestimate the particulate matter mass. Finally, the air collection filter should be as close to the outside of the duct or stack as possible. Running the particle laden air through extended lengths of tubing before the filter, as is sometimes done, will certainly result in particle loss and underestimation of particle mass.

Finally, if the collection medium is subject to pressure changes as dust accumulates, this may slow the flow of air in

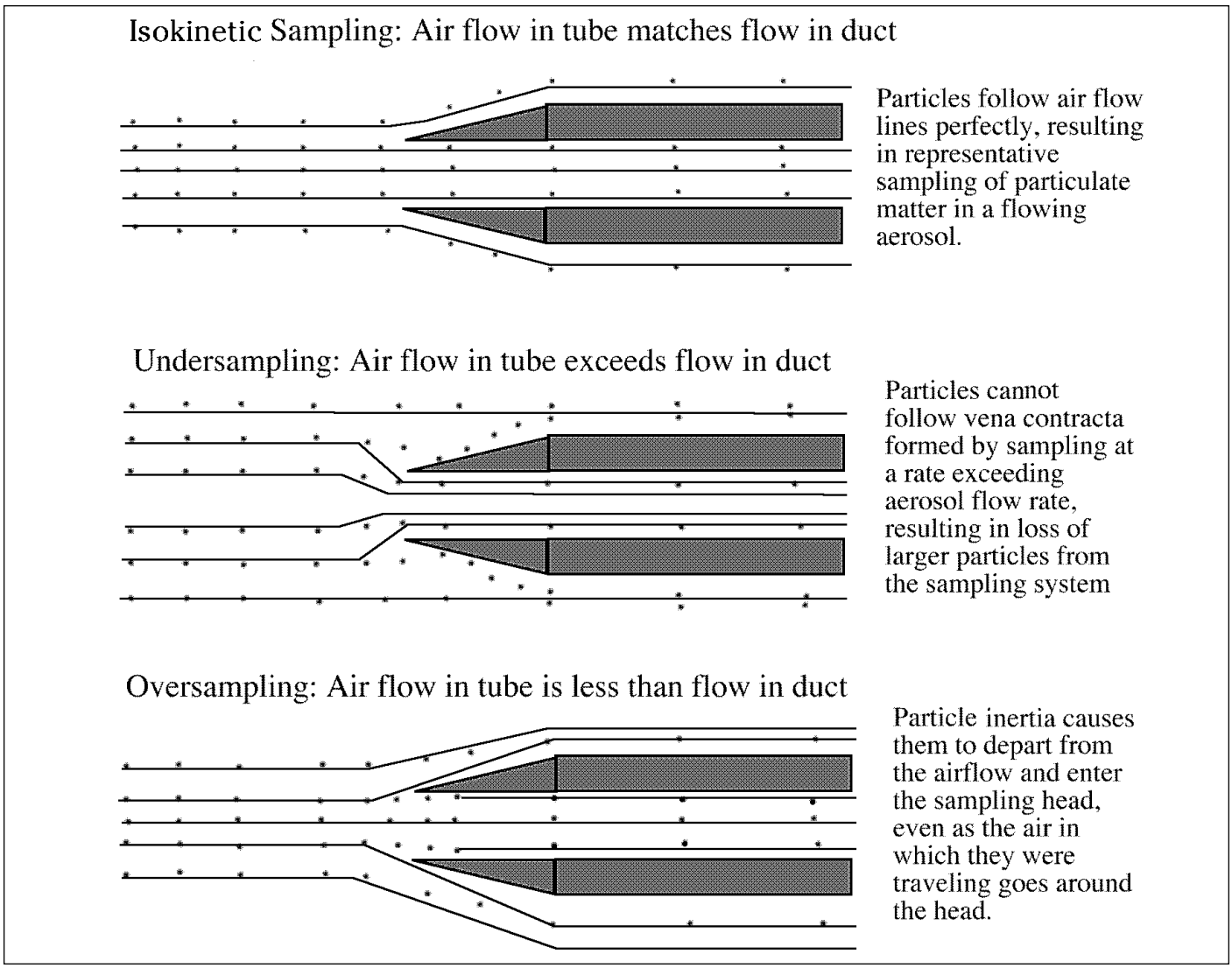

Figure 8–10. Sampling error introduced by nonisokinetic sampling.

the system and drop the sampling flow rate below the isokinetic level. This can be avoided by using a sampling medium that does not change resistance substantially with loading (e.g., water collection), or controlling the flow either actively or via a critical flow orifice.

If the temperature or airflow rate in the duct or stack is subject to change during sampling, it will be very difficult to maintain isokinetic conditions without constant attention. In a nicely flowing system, in contrast, once the system is set, it should operate reliably on its own.

Surface Sampling for Particulate Matter

Surface sampling in some workplaces is useful as an adjunct to air sampling. Typically, surface sampling is conducted for several reasons.

First, surface sampling is conducted to determine adequacy of housekeeping and engineering controls in minimizing the spread of highly toxic PM. Surface sampling is not needed where the contaminant is of low toxicity, as a visual observation will usually suffice. However, for materials with high toxicity and correspondingly low occupational exposure limits, surface sampling should be considered. In the facilities owned or operated by the Department of Energy, surface sampling of beryllium work areas is required. In U.S. Housing and Urban Development (HUD) housing (also used more broadly in other settings), surface sampling for lead dust is required. A little utilized but potentially very useful type of swipe is the *Ames test* swipe. Here, if there is no specific analysis for the potentially mutagenic material (e.g., soot), subjecting the surface dust to revertant mutation assay provides some semiquantitative data about the potential spread of that material.

Federal OSHA has no specific requirements for surface sampling for particulate matters, but does require that if such sampling is conducted in the workplace, it be treated the same as air sampling data with respect to records retention.

Other settings where surface sampling for PM is useful include the following:

- ➢ When working on laboratory fume hoods, to verify that no potentially explosive perchlorate residue is present in the hood, plenum, duct, or fan.
- ➢ Prior to releasing excess equipment for reuse, utilization, sale, or donation. For example, it would be inappropriate to donate a machine tool contaminated with beryllium or other highly toxic metal to a local high school.
- ➢ When it is necessary to determine what metals are/were used in an area, surface samples can be analyzed for many metals by inductive coupled plasma emission spectroscopy or similar tool.
- ➢ Where the contaminant has a high percutaneous toxicity, as in the case of some organophosphate pesticides.
- ➢ Where the surface dust is a major component of the source term for airborne exposure.
- ➢ Following certain types of abatement actions (lead in particular) to verify the adequacy of the decontamination and contamination control procedures.
- ➢ Whenever working with potentially radioactive PM.

A variety of surface sampling techniques are available to the industrial hygienist. The traditional method is a dry "swipe" sample, where the surface is rubbed over a known area with a mixed cellulose ester filter or a special swipe tab often called a "smear tab." These are quick and easy, and it is common to combine samples from several related areas onto one swipe, but this is also the least reliable, most user-specific surface sampling technique.

A move up from the dry swipe is the wet swipe, where the Whatman filter or swipe tab is prewetted with water or another liquid prior to application to the surface to be tested. This procedure is a little more precise than the dry swiping methods, but still subject to a lot of variability.

The Housing and Urban Development (HUD) procedure for lead dust sampling introduced most industrial hygienists to the process of wet wiping, using a large, wet wiping medium and a specified wiping technique. While still very much semiquantitative, this procedure is generally regarded as an advancement over prior wipe sampling methods, with the possible exception of the radiological control community. An American Society for Testing Materials (ASTM) draft procedure for lead wipe sampling was proposed in 1993, which evolved into an ASTM Provisional Procedure in 1996 (ASTM 46-96). Many other wipe sampling methods for lead have been published, including EPA 3050.

Where visible quantities of dust are present, surface samples can be obtained simply by collecting the dust and sending that in for analysis. A common variation on this is the surface *microvacuum* technique. Microvacuuming is usually performed by using a standard 25-mm or 37-mm mixed cellulose ester filter attached by hose to a relatively high flow rate pump. A short extension tube, cut off at a 45-degree angle on the front end, is attached to the front nipple on the cassette. A known area of surface is carefully vacuumed onto the filter, and the entire cassette is submitted to the laboratory for analysis. Sometimes the desired result is mass of contaminant per mass of total dust (i.e., percent or ppm) or mass of contaminant per given surface area (e.g., micrograms per square foot). The ASTM has developed two specific standards for microvacuuming for asbestos fibers, ASTM D 5755 and 5756.

A variation on this procedure that is somewhat more elegant is the "Smair Ring." This machined ring takes the place of the top cap on a three-piece air filter cassette. Numerous small holes are drilled into the side at specific angles, designed so that when the ring is placed flat against the surface to be sampled, high velocity jets of air were driven onto the surface to dislodge dust and create a vortex effect, efficiently removing the dust and loading it onto the surface. The only drawbacks to the Smair ring are its relatively high cost, limited commercial availability, and its ineffectiveness on uneven surfaces. Other devices similar to a Smair Ring have been developed and marketed.

Direct-reading surface sampling tools also exist. Lead on surfaces can be detected by the use of sodium rhodizinate-based swipes meeting the specifications of the NIOSH 7700 method. Although lacking the sensitivity and specificity of the more traditional field collection/lab analysis method, the advantage of instantaneous results, at least for screening purposes, is substantial in some settings. Similar single-use surface sampling tubes are available for mercury droplets, nickel dust, cadmium dust, and chromate dust.

All surface samples of PM should be regarded as qualitative or at best semiquantitative, and used as an adjunct to air sampling and other aspects of a comprehensive industrial hygiene program. See Chapter 17 for more information on direct-reading instruments.

Dermal Monitoring

A related type of PM monitoring is dermal monitoring, typically for particles that present significant skin absorption hazards, such as pesticides. NIOSH 9201 is a method that was developed to measure chlorinated and organonitrogen pesticides from patches of fabric attached to the clothing of workers. One product available to implement this method is the "*Dermal PUF (polyurethane foam) patch*." It is a section of polyurethane foam fabric that is clipped to the worker's clothing or taped directly to the skin. After sampling, the patches are removed and sent to a laboratory for analysis of the pesticide.

Analysis of hand washing rinsate is another technique sometimes used to evaluate dermal exposure. Increasingly common, at least in research, is the use of ultraviolet fluorescent powders added to pesticides or other chemicals that can then be imaged and recorded photographically. This is an old trick used in the training of radioactive material handlers: have the trainees handle fluorescent powder instead of radioactive powder and at the end of the exercise, demonstrate with a long wave ultraviolet light the spread of contamination and problems in their practices.

ANALYSIS OF AIR SAMPLES

Once the particle is removed from the airstream and collected onto a filter or into a liquid, it then must be analyzed. Historically, the most common methods of analysis were optical microscopy, gravimetric (weighing), and sometimes wet-chemical analysis. While these methods are still fairly common, more sophisticated analytical procedures have been developed for all metals, free crystalline silica, certain organic materials, isocyanates, and certain other materials.

Metals (Spectroscopic Analysis)

Wet-chemical analysis of most metals ended with the advent of the flame emission photometer, a device that siphons dissolved metal ions into a flame and measures the characteristic optical emission lines of the metal. The intensity of the lines is proportional to the concentration of the metal.

The flame photometer was improved by the introduction of the flame atomic absorption photometer. Here, the flame-excited metal ion is exposed to a collimated beam of light created by a source that produces the emission lines characteristic of that metal. The ions in the flame absorb the intense light in proportion to their concentration. This method has the advantage of being more stable and sensitive than flame photometry, but is also more expensive and limited, as it requires separate light sources for each element to be analyzed. A further improvement, still in broad use, is the graphite furnace atomic absorption spectrophotometer, where the flame is replaced by a graphite furnace.

The next major improvement in metal analysis, which is the workhorse instrument in most sophisticated labs that perform many different types of metal analyses, is the inductively coupled plasma atomic emission spectrometer (ICPAES). Here, the flame is replaced with very high temperature gas plasma, created by induction from the fields created by a radiofrequency generator. Other than changing the excitation source and computerizing the operation of the device, an ICPAES operates largely like an old flame photometer. The liquid containing the digested metal ions is siphoned into the plasma, and as it is turned into plasma it produces characteristic emission lines. A monochrometer allows selection of a particular line, and the intensity of that line is proportional to the concentration of metal analyte. Typically, it is possible to automatically scan the different lines to determine many metals at the same time, and to compare the intensity of several lines produced by a metal to assure that no positive or negative interference is occurring. A further improvement of this device eliminates the monochrometer and photometer, and replaces them with a spectrometer consisting of a light dispersion element (e.g., reflective diffraction grating) and a charge coupled device that allows simultaneous measurement of all lines of all elements.

The last big step in analytical instruments for metals is the inductively coupled plasma-mass spectrometer (ICP/MS). In this device the metal ion is first run through radiofrequency induced plasma, and then directed into a mass spectrometer, which weighs the atom to determine its exact atomic number and concentration. Like the ICPAES, this instrument can analyze many metals all at the same time. For many metals, this is the most sophisticated and sensitive routinely used analytical instrument. It should be noted that in many cases, such sophistication and sensitivity are unnecessary and needlessly expensive. For routine analysis of a single analyte like lead, a simple atomic absorption spectrophotometer is perfectly adequate and much less expensive than an ICP/MS. The ICPAES and ICP/MS are very helpful when you need low detection limits, do not know the exact metal composition of the PM you are sampling, or require the analysis of several metals on the same filter.

Free Crystalline Silica

Free crystalline silica (e.g., quartz, cristobalite, and tridymite) can be analyzed by a couple of methods. One involves infrared spectrophotometry, as in the NIOSH 7602, 7603, and MSHA P-7 methods. Colorimetric methods are still occasionally used. However, the most common and reliable analytical method is powder x-ray diffraction, as in NIOSH 7500 and OSHA ID 142. This method is more sensitive and precise and can analyze all three free crystalline silica species at the same time. It can be used for personal air samples, settled dust samples, bulk samples, or high volume air samples. In the past, it was considered necessary to submit either high volume samples or at least settled dust samples along with the air samples, in order to allow proper calibration of the instrument. In recent years, many laboratories no longer require the cosubmission of high-volume or settled-dust samples, although if the concentration of silica in the source material is not known, it is a prudent practice to submit a settled-dust sample or bulk sample to ascertain this value.

Unfortunately, both of the main analytical methods available for free crystalline silica are quite imprecise by industrial hygiene standards. The variability among labs or even within labs is quite high, with a relative interlaboratory standard deviation up to about 40 percent for the infrared method. The variability is much improved, albeit still poor (SD in the range of 20 percent) for the x-ray diffraction method. Among common analytes, only the analysis of asbestos approaches the level of analytical imprecision characteristic of silica analysis (asbestos analysis SD about 20 percent at best).

Asbestos

Asbestos is still measured mostly by optical techniques. From about 1925 until 1969, asbestos-containing dust in the United States was usually collected in a water-filled impinger. An aliquot of the impinger fluid was placed in a special well slide and fibers were counted through an optical microscope. Results were expressed in terms of millions of particles per cubic foot of sampled air (mppcf). (Note: There are a few OSHA standards that still exist only in terms of mppcf, namely soapstone, talc, cement, and mica.)

Following the lead of the British and publication of the membrane filter method in the United States (Lynch & Ayer, 1968), in 1968 the United States adopted a filter sampling method that still allowed optical analysis. A wedge of the filter, with fibers embedded, is cut from the whole, placed on a slide, and the filter wedge is rendered transparent by the application of a drop of solvent. The fibers are then counted through the eyepiece of a phase-contrast microscope using a Porton-type reticule. Fields are semi-randomly selected, and if the particle is at least 5 μm long, has an aspect ratio of 3:1 or greater, and falls within the bounds of the engraved reticule, it is counted. The results are now expressed in units of fibers per cubic centimeter of air (f/cc, occasionally f/mL), very difficult to relate to the older mppcf units. Many attempts have been made to correlate the two units, but the conversion factors have typically been found to be of limited applicability. Still, the original OSHA standard in terms of f/cc is based on one conversion factor from mppcf.

The National Institute of Occupational Safety and Health and OSHA adopted essentially the same method after OSHA's creation in the 1970s. Originally called Physical and Chemical Analytical Method 239 (P&CAM 239), over time several changes to the method have been made (changing to a Walton-Beckett reticule, replacement of the liquid clearing solution with a vapor phase clearing chemical, adjustment of acceptable flow rates, resolution testing of the microscope), and the method was renumbered NIOSH 7400 in 1984. It has been through several revisions since, but retains the designation NIOSH 7400. Currently, the most recent revision is 1994. OSHA adopted the new NIOSH 7400 in lieu of the P&CAM 239 method almost verbatim when it revised the asbestos exposure standard in 1986. In this case, they called it the OSHA Reference Method.

Other less commonly used optical analytical methods for asbestos also exist, including the OSHA 160 method and the Asbestos International Association Membrane Filter Reference Method RTM 1.

The analysis of asbestos by optical methods is usually quite imprecise and often inaccurate. Especially at low fiber loading on the filter, the imprecision of the NIOSH 7400 method is severe, as shown in Figure 8–11. Assuming proper procedures are used, the equipment is adequate and well set up, and the analysts well experienced, the variability seen at the low end of the fiber loading curve is largely intrinsic to the method and random in nature. Imposed on the inevitable error is the tendency of less skilled analysts to over-count fibers at very low loading. At excessive fiber loading not shown in Figure 8–11, systematic undercounting of fibers starts to occur, eventually reaching the point where the filter is not analyzable. The method is best used by controlling fiber loading to levels between 100 and 1,300 fibers/mm^2 of filter surface area, which can be back-calculated from the expected airborne asbestos concentration, given that the usable surface area of the 25-mm filter used for asbestos collection is 385 mm^2. For example, if the expected fiber concentration is 1.0 f/cc, in order to get the desired loading on the filter, the sample volume should be from 38 to 490 liters.

The inaccuracy of optical methods of asbestos analysis arises from the fact that the analyst counts all fibers that meet the method specifications, not just asbestos fibers. In addition, the limited resolution of optical microscopes (about 0.25 μm for most phase-contrast microscopes) means that the narrowest and potentially most toxicologically significant fibers are systematically undercounted. While a significant percentage of the fibers of amosite (20–60%) will usually be visible under the optical microscope, only a small fraction of those of chrysotile and crocidolite asbestos will be visible. This fraction, depending on the analytical methods used, may be as low as 1–5 percent.

If they are present, fibrous glass, cellulose, and mineral wool fibers get counted as asbestos fibers. Within the rules for NIOSH 7400 and for the OSHA Reference Method, there are no provisions for discriminating among different types of fibers, even though a skilled microscopist can readily tell a cellulose fiber from an asbestos fiber. The method authors are well aware of this limitation, and the NIOSH 7400 method is actually termed the analysis of "Fibers," not asbestos.

The counting of particles with an aspect ratio as low as 3:1 results in the enumeration of "pseudofibers." While true asbestos minerals have aspect ratios of 10:1 or more, many minerals, including many nonasbestiform polymorphs of asbestos and other minerals like talc, form cleavage fragments or scrolls which are somewhat fibrous but clearly not asbestiform, but must be counted under the NIOSH/OSHA methods.

Finally, the NIOSH "A" counting rules and the OSHA method require counting all fibers meeting the length and aspect ratio rule, regardless of their diameter. The Asbestos International Association method RTM 1 discounts fibers wider than 3 μm. The rarely used "B" counting rules offered in NIOSH 7400 makes the same concession. Research has suggested that fibers, regardless of length, tend to demonstrate AEDs that are about three times their width. Three times 3 μm is 9 μm, and when multiplied by the density of asbestos which exceeds 1, makes such wide particles essentially nonrespirable and toxicologically of low significance.

These nonspecific analytical methods were developed primarily with work settings such as asbestos mines, mills, and asbestos manufacturing facilities as the target. In these settings, most of the airborne fibers are asbestos. In modern times, at least in the United States, these are not major industries. Asbestos exposure and therefore asbestos monitoring are now mostly associated with building maintenance and renovation and asbestos abatement. In these settings, asbestos exposure usually occurs along with other fibrous or pseudofibrous materials, often making the measured

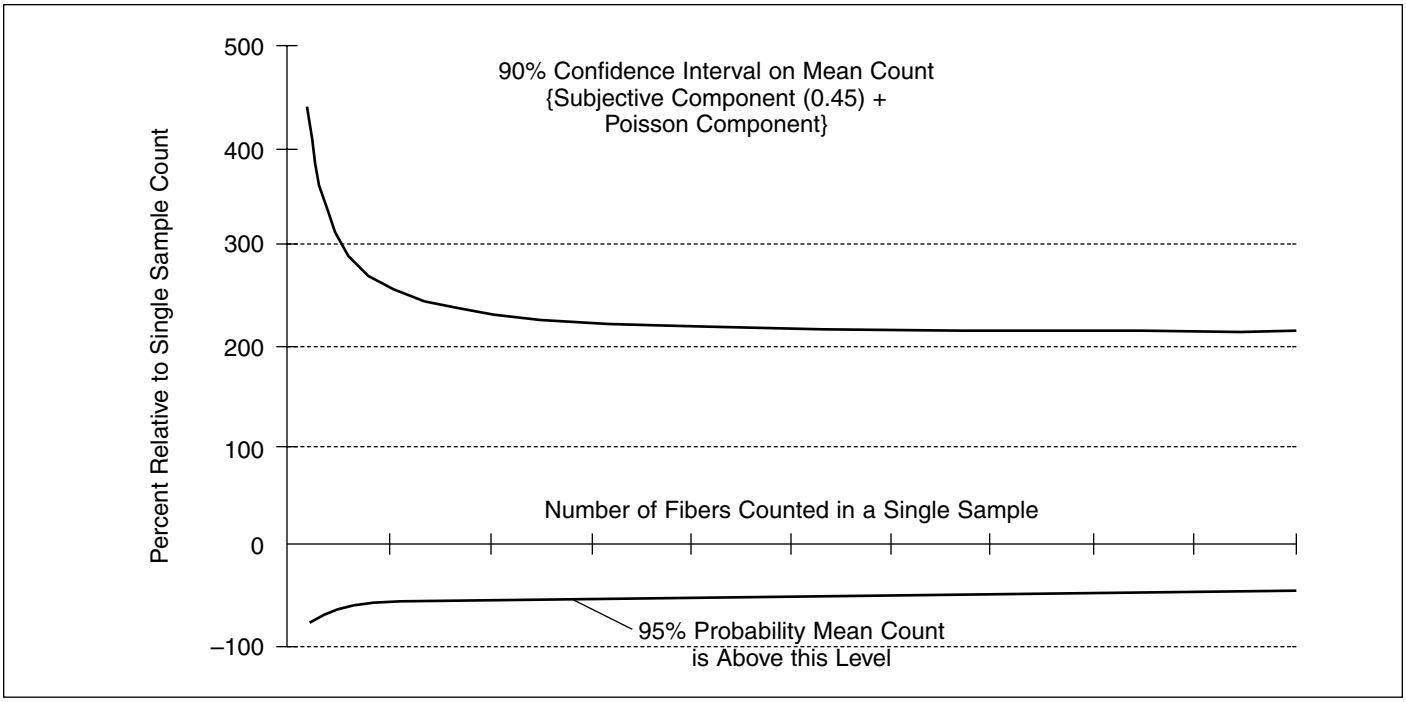

Figure 8–11. Variation in precision of NIOSH 7400 with fiber loading.

"asbestos" exposure a severe overestimate. Perhaps the worst example of this occurs during controlled removal of sheet rock with asbestos-containing surface coating or joint spackling. Fiber exposures when measured by phase-contrast microscopy (PCM) in accordance with the NIOSH or OSHA methods can be very high, but if subjected to analyses that allows discrimination between asbestos and nonasbestos fibers, few of the fibers counted by optical microscopy may turn out to be asbestos.

Several methods are used to get around the inherent nonspecificity of phase contrast optical fiber counting. In some cases, experienced optical microscopists can simply discount obvious nonasbestos fibers and count only those fibers that are likely to be asbestos. This method, however, it subject to the experience of the microscopist, and is more of an art than science. Alternatively, procedures have been developed (OSHA ID 160) which allow phase contrast counting microscopy to be used in tandem with polarized light mineralogical analysis (PLM), morphological observations, scanning electron microscopy (SEM), and transmission electron microscopy (TEM). This procedure is designed to be used by OSHA compliance officers when they sample for asbestos in a multifiber aerosol environment.

The Asbestos International Association has developed a scanning electron microscope procedure, RTM 2, as has the International Agency for Research on Cancer, but these are rarely used. The most common method for differential fiber counting is transmission electron microscopy. It is routine to consider fiber morphology in determining if they are asbestos under the electron microscope. Also, individual fibers beamed with electrons emit soft x-rays characteristic of elements in the fiber. If the asbestos under analysis is chrysotile, a magnesium silicate, very large peaks should represent magnesium and silicon only. If the fiber also contains a large peak for iron, it could be crocidolite, aamosite, or actinolite. Many other interfering fibers would lack one or more of these major components. This qualitative analytical tool is called *energy dispersive x-ray fluorescence*.

A more definitive differential technique with the electron microscope is electron diffraction patterns. Selected area electron diffraction (SAED) patterns are quite specific for chrysotile and fairly specific to the amphibole series. Combined with morphological observations and qualitative analysis, TEM can provide nearly definitive asbestos differentiation.

One of the earliest TEM methods specifically designed for asbestos analysis was the EPA method of 1978, named after its principal author, A. Samudra. These early TEM analytical methods expressed asbestos concentrations in gravimetric terms, nanograms per cubic meter (ng/m^3). This archaic unit, analogous to the use of mppcf in the early days of optical asbestos analysis, was replaced in the early 1980s.

A long-useful electron microscope method published in by the EPA in 1984 is usually called the *Yamate* method, after its principal author George Yamate. Here and in subsequent TEM methods the unit of measure is "asbestos structures per cubic centimeter of sampled air (s/cc)." This included asbestos fibers, bunches of asbestos fibers, clustered fibers, sets of fibers sticking out of other materials, etc.

When the Asbestos Hazard Emergency Response Act (AHERA) was signed into law the EPA developed a new TEM method, usually just called the AHERA method (40 *CFR* Part

763), which differs in some ways from the Yamate method. It is more than just an analytical method, as it is tied in with sampling protocols required of schools in other parts of the AHERA-driven regulations. Still, it can be teased away from these additional school requirements and used in various ways in nonschool settings. NIOSH also has a TEM method numbered 7402. The AHERA and NIOSH 7402 methods are probably the most commonly used TEM analytical procedures for asbestos.

TEM analysis is also the fix to undercounting narrow, toxicologically important fibers in optical analysis. TEM can visualize all asbestos fibers, even the narrowest, with no difficulty. Thus, TEM analysis of asbestos can be both highly specific and highly sensitive. At low fiber loading, it can still suffer from the inherent statistical variability associated with counting discrete data instead of measuring continuous data. This can be improved by counting more than the recommended number of microscopic fields, or better, by providing a filter with a higher fiber loading.

Historically, the biggest drawback of TEM analysis has been high cost and slow turnaround. As the asbestos abatement and handling industries have evolved from a novelty job to just another commodity, the time and money costs of TEM analysis have plummeted. It is still more expensive than PCM analysis, but unless the PCM lab is on-site, the turnaround time for TEM almost matches that of PCM. Another major problem with fiber type-specific analysis protocols is that they are generally not addressed in the OSHA regulations. However, since even the OSHA laboratory in Salt Lake City makes use of fiber-type specific counting, it is clear that there is some leeway here if the methods are sound and carefully applied.

Radioactive Particles

Radioactive particles are collected on filters, with the exception of activated charcoal sampling of radon as described in the sampling section of this chapter. Filters can be submitted for analysis by several means, almost all of them taking advantage of the readily detectable alpha, beta, or gamma emissions.

In many jobs, people handling radioactive materials are handling only one element at a time. Thus, simple counting of total emissions gives a picture of the total amount of that radioactive material on the filter. Knowing the radioelement, the amount of radioactive material in the air can be compared to the derived air concentration, which is a year-long weighted exposure limit. This is often termed *gross alpha, beta, gamma analysis*. Only if the radioisotope analyzed is in question or completely unknown (as might occur in working in multielement contaminated legacy facilities or waste disposal sites) is more sophisticated analysis necessary to differentiate radioactive materials based on the energy and type of their emission (radiospectroscopy).

Analysis of filters is often performed nondestructively by counting with a gas-proportional counter or more often, a solid state scintillation detector. Solid-state scintillators emit a burst of photons when hit by a radioactive emission within their range of sensitivity, and a sensitive photomultiplier tube typically detects this. Because only one surface of the filter is exposed to the detector crystal, compensation must be made for the geometry, and the results are typically increased by a factor of two or more to determine the complete emission rate. The exact correction value is determined empirically with a standard source.

In place of the solid state scintillator is often a Geiger-Mueller (GM) tube, which is useful for gamma and higher energy beta emissions. Geiger-Mueller tubes do not typically perform well for alpha particle emitters, so when measuring alpha emission, the solid state detector would be more appropriate.

An alternative type of analysis, which does destroy the filter, is liquid scintillation counting. In this equipment, the filter or particles removed from the filter are placed in small vials, to which is added a fluor. The fluor will act like a solid-state scintillation crystal and will give off a burst of light when stimulated by a radioactive decay. This light is detected by a photomultiplier tube, and after passing through a coincidence gate to compensate for thermal noise and cosmic radiation, and compensation for internal "quenching," is counted as a radioactive decay. One of the big advantages of this method is it can detect very low energy emissions, such as the weak beta particle released by tritium-containing particles (an isotope of hydrogen with three neutrons in the nucleus of the atom).

Many of these types of instruments come in simple versions, some of which are field-portable, and more sophisticated laboratory versions, sometimes with radiospectroscopic capability.

Under some circumstances, it is advantageous to analyze radioactive particles by chemical means rather than by radiodetection means.

Gravimetric Analysis

A shrinking list of particles are still analyzed gravimetrically, that is, by simply weighing the PM collected.

With the advent of more sophisticated and specific analytical tools, gravimetric analysis is used most often when sampling for "nuisance dust" or PNOC. Materials still analyzed gravimetrically are shown in Table 8–J.

Note that many agents that can be analyzed gravimetrically could also be measured by much more specific means. Fibrous dust can be analyzed microscopically, oil mist chemically, the metals by ICPES. In a mixed-dust environment, it is much better to use the specific analysis than the gravimetric analysis.

Several compensations must be made in order to be able to weigh dust collected on a filter. These must accommodate the unknown weight of the filter as it arrives from the manufacturer, and the potential for water absorption by the filter or collected dust during the sampling or analysis procedure. Without knowing something about the "tare" weight of the filter, it is

Table 8–J. ***Materials Still Commonly Analyzed Gravimetrically***

Cement	Coal dust (<5% silica)	Cotton
Emery	Fibrous glass*	Glycerin
Graphite	Gypsum	Grain dust
Kaolin	Limestone	Magnesite
Marble	Metal working fluids	Mineral wool (occasionally)
Oil mist	Palladium	Paper fibers
Plaster of paris	Soapstone	Starch
Sucrose	Talc (<1% asbestos)	Titanium dioxide
Wood dust	Zinc oxide	

* Recent TLV analyzes fibrous glass microscopically as well as gravimetrically.

impossible to weigh it and know how much of the mass is filter and how much is collected PM. If the original weight of the filter is known prior to sampling, it may change if it or the collected PM is hydroscopic and gains weight from atmospheric water vapor, again making analysis difficult or impossible.

In the traditional procedures, the collection filter is desiccated by vacuum, and then immediately tared to obtain a base weight. It is assembled into a sampling cassette, with the tare weight written in a log corresponding to a numbered cassette, or written directly on the cassette, or both. The filter is then used to sample for dust in the field and returned to the laboratory. The filter is vacuum-desiccated a second time. The dry filter is then immediately weighed on a highly sensitive Mettler-type balance or a Cahn-type electrobalance. The difference in the final weight and the tare weight is the total dry dust collected. When divided by the sample volume, the airborne concentration of dust is determined.

Commercially preweighed filters tared to 10 ng are also available, but these are not run through the desiccation process on either end of the analysis. The use of hydrophobic PVC filters minimizes the effect of atmospheric water on the filter, but does not compensate for atmospheric water absorbed into the particulate matter on the filter.

A more convenient although probably less precise method of measuring PM gravimetrically is the use of stacked matched-weight filters. Starting with low-water absorbing filters (PVC typically), the manufacturer or laboratory weighs out many of the same filters, pairing sets which happen to weigh about the same. These "matched weight" filter sets are stacked and loaded into a single filter cassette. The filter is used to sample for gravimetric analysis and submitted to the laboratory. In the lab, both the collection filter and the "control" filter are weighed without any special pretreatment. The difference in weight is the total dust collected. An assumption is made that any weight gain of the filter caused by water absorption affects both filters equally and the blank value can be used to adjust the sample filter result.

Matched-weight filters are much more easily analyzed than the more traditional desiccation/tareing procedure. But because of a lack of compensation for water absorption by the collected particles, and small variation in weight between the "matched" sets of filters (commercially, 25-100 µg), this method is generally considered less accurate. When sampling and analyzing for an agent like nuisance dust or PNOCs, which have comparatively high occupational exposure limits, these effects become unimportant, and matched-weight filter sampling is common and accepted. If sampling for an agent with a lower exposure limit, with the intention of gravimetric analysis, the desiccation/tared filter method is preferred.

Biological Organisms

Biological organisms most often of interest to the typical industrial hygienist are limited to bacteria, fungi, and viruses. Analysis of some biological organisms has improved dramatically just within the last couple of years. The analysis of fungal spores is a good example. Traditional sampling methods pick up only viable spores by collection by inertial impaction onto a growth medium or into a special type of impinger. The spores are grown on the collection or plating medium (in the best case, a couple of different media) in a controlled environment until the individual spores establish colonies. The plates are allowed to grow as long as possible, but curtailed before the colonies start to merge or overlap. Then, the plates are placed on a gridded, illuminated stage called a *plate counter* and the total number of *colony-forming units* (*CFUs*) is counted either with the naked eye or a low-power magnifying glass.

In 1986 the ACGIH established an occupational exposure standard, using the direct impaction of viable particles onto growth agar with analysis of total viable CFUs/m^3. One could also take samples inside a workplace and outside to determine if there were more viable spores in the building than in the ambient air (an occurrence referred to as *amplification*). Inherent in this standard is the assumption that a colony is a colony, and thus a spore is a spore, and the genera and species do not matter. In fact, this early attempt at establishing a standard considered fungal spores primarily as an allergenic bioaerosol, in particular as contributors to indoor air quality problems. While this standard was useful in many circumstances, and the ACGIH should be applauded for leading the effort to establish standards for fungal spore occupational exposure limits in office environments, it soon became apparent that the standard is too simple for many settings.

The first problem surrounds the issue of viability. Many airborne spores are dead, including up to 90 percent of the spores of *Stachybotrys chartarum* (formerly *Stachybotrys atra*), a still-controversial but almost certainly toxic spore. These dead spores will never grow on any growth media, and thus their number will be greatly underestimated by viable sampling yet the spores remain toxic.

Further different genera and even different species require different growth media to prosper. The standard microbio-

logical media suggested in the 1986 standard are good at supporting growth of many common fungi, but not all of them, and not some of the more problematic. Once again, *S. chartarum* serves as a good example. The media commonly used are poor substrates for the proliferation of this toxigenic fungus. When sampled in a mixed spore environment, it is almost certain that *S. chartarum* will be poorly detected, even if living spores are collected. Other spore types will grow much more vigorously, and the culturing period will have to be suspended long before any growth of *S. chartarum.* It is necessary to use a high-cellulose growth medium for *S. chartarum,* traditionally Czepak 10-percent cellulose agar, or more recently, corn meal agar. Another way to avoid the viability problem is nonviable sampling, which can be done with a Burkhart Spore Trap or other similar instruments or by using an Air-O-Cell cassette. The collected spores are then counted under a microscope, usually with determination down to the genus level, and their viability or ability to grow on available media is irrelevant. However, the analysis typically requires a much more sophisticated analyst than is needed for simple colony enumeration without genus identification.

The second major problem with earlier fungi sampling procedures is the lack of specificity. Generally, industrial hygienists just counted all of the colonies appearing on the petri dish, and compared the net count per cubic meter to the ACGIH standard. On some occasions, when the expertise was available, the genus of the colonies might be determined, although separate standards were not available for genera and not much was known of their specific pathogenic properties.

The lack of specificity resulted in two problems. When comparing outside to inside samples using gross colony counts, the colony count might be the same, but the genera on the two samples might differ radically. When this occurs, it is usually true that the outside spores, usually "phyloplane fungi," are being removed from the incoming air by filtration in the air supply units, and the different set of organisms seen in the building is due to internal growth sources, often with much more hazardous fungi. A problem with amplification of spores inside the building might go unnoticed.

Gross colony counting also ignored the obvious problem, that different fungal spores have different health consequences. While it is possible to become allergic to almost any type of fungus, some genera and species are more likely to cause problems than others. Even more important, fungal spores vary radically in terms of acute and chronic toxicity, even within the same genus. There are at least 160 identified species of penicillium mold, some of which are not known to produce any *exomycotoxins,* but others produce potent toxins. Inhalation of spores of toxic species can cause significant toxic responses, whereas nontoxin producing species only cause allergy and other types of irritation. The same problem exists with other large genera, such as *Aspergillus* and *Fusarium.*

While determination of genus by optical microscopic examination (including the analysis of genus by observation of spores captured in a Spore Trap or in an Air-O-Cell cassette) is relatively straightforward for a microbiologist, determination of the exact species in large genera is much more complicated. Often it requires growth on multiple media, extensive microscopy, and a highly skilled analyst. This takes time and is expensive. Recently, several U.S. laboratories have started to offer speciation based on matching the DNA of cultured spores to banked DNA segments. The results are reported as the species. This procedure is almost certain to largely replace standard optical microbiological speciation at least for highly diverse genera.

Still, the practicing industrial hygienist is left without hard guidelines or occupational exposure limits on a species by species basis. Other countries have adopted guidelines, at least for certain settings (e.g., schools). Canada has a zero tolerance policy for known exotoxigenic species in schools and some other public buildings. Some European countries also have occupational exposure limits. In the United States, the rules remain rather vague: if amplification of a mold is found inside a building, work to track down the source and remediate it. If amplification of a potentially toxigenic species is found, consider more aggressive action, such as hiring experts in the area of detecting these organisms and specialized remediation firms. In extreme cases, many buildings, public and private, all across the United States have been evacuated until serious mold problems could be mitigated.

Actually, with toxin-forming species of fungi, even speciation by DNA matching leaves a certain level of uncertainty in assessing hazards. Any given species, indeed any given colony of potentially toxigenic mold, may or may not produce and release toxins under the conditions of growth. Most toxins are released into the environment when the mold sporulates, which it does when conditions for vegetative growth start to deteriorate. Depending on factors poorly understood, these spores might contain high levels of toxins or very low levels of toxins. Thus, the ultimate air sampling to determine the hazard posed by airborne mold might be to subject the collected spores to chemical analysis for mycotoxins known to be associated with the species. Unfortunately, this is still primarily a research tool or a semiquantitative agricultural tool, not widely available in a sensitive form to the industrial hygiene community. Another untapped analytical resource is cytotoxicity testing, where the mold extract is added to a growing colony of animal cells, and any adverse effect of the mold-extract on cell growth or survival provides a general indicator of the mold's toxicity. This procedure has the advantage that you do not have to know or guess at the toxins present to effectively use the method, as is necessary for chemical toxin analysis.

A major component of noninfectious airborne bacteria that may contribute to their ability to cause allergic extrinsic alveolitis or other less serious lung effects is endotoxin, a portion of the cell wall of gram-negative bacteria. As

Table 8–K. *Examples of Organic Particulate Matter Analysis by Various Chemical Means*

Agent	Analytical Tool	Method Number
Polynuclear aromatic hydrocarbons	High-performance liquid chromatography (HPLC), gas chromatography (GC)	NIOSH 5506, 5515
2-Acetylaminofluorine	HPLC	OSHA Chemical Sampling Information
Acridine	HPLC	OSHA 58
Alkaline dusts	Acid titration	NIOSH 7401
Ammonium sulfamate	Ion chromatography	OSHA ID 188
b-Benzene hexachloride	GC	EPA IP 8A
t-Butyl chromate	Differential pulse polarography (DPP)	OSHA 1D 103
Carbaryl	Visible absorption spectrophotometry	NIOSH 5006
Chromium, hexavalent	Ion chromatography-electrolytic conductivity detector	NIOSH 7604
Crag® herbicide	Colorimetric photometry	OSHA Chemical Sampling Information
Cyanide ion	Ion-specific electrode	NIOSH 7904, OSHA ID 120
Dimethyl arsenic acid	Ion chromatography-atomic absorption	NIOSH 5502
Elemental carbon (surrogate for diesel exhaust)	Evolved gas analysis with thermal analysis sensor	NIOSH 5040
Bacterial endotoxins	Limulus method	LAL method
Mycotoxins	Cell cytotoxicity	Experimental
N-nitrosodiethanolamine	GC-thermal energy analyzer	OSHA 31
Oil Mist	Fluorescence	OSHA ID 128
Oil Mist	Infrared spectrophotometry	OSHA ID 178, NIOSH 5026

described previously, this is collected on filters or in impingers. Subsequently, the endotoxin can then be analyzed chemically or biologically.

For the most part, bioassays are used, the most common being the *Limulus amebocyte lysate* (*LAL*) test. This procedure is simple, sensitive, and quick. The LAL determines the approximate bioactivity of the endotoxin present in the sample rather then the physical amount. The bioactivity is the most important characteristic. The analytical method has some constraints depending on the source of the sampled bacteria or fragments, contaminants, and specifics of the analytical process. One highly touted specific method is the *Kinetic Limulus Assay with Resistant-Parallel-Line Estimation* (*KLARE*). The results are reported in terms of "*endotoxin units* (*EUs*)," which is useful for comparison to control samples. There is no widely accepted guidance standard to which to compare the results.

A very standardized method has been proposed recently (Milton, 1995).

Organic Particles

A wide range of analytical tools, including gas chromatography and high-performance liquid chromatography are used to analyze organic particles collected on filters. Table 8–K lists organic PM commonly analyzed by these other types of chemical analyses.

Gas chromatography-mass spectrometry is sometimes used where very high sensitivity is needed or the composition of the dust is diverse or unknown. Tandem GC mass-mass spectroscopy is used for extreme sensitivity against a high background of similar organic molecules (e.g., mycotoxins in spores).

Direct-Reading Particle Detectors

Direct-reading particulate matter samplers are available and commonly used under conditions that do not change very much or for process control. Direct-reading instruments are the sample collection device and the sample analysis device, all in a field portable format. The results are provided immediately, as there is no delay for laboratory analysis.

A few grab-sampling *detector tubes* can be used for particles, such as oil mist, nickel, chromic acid, ethylene glycol, and sulfuric acid mist. More commonly, electro-optical particle enumeration devices are used. The earliest generation of these devices (many similar devices are still in use today) were forward (usually) light-scattering photometric dust monitors. The aerosol is passed continuously through the device, illuminated by a light, and the amount of forward-scattered light is detected and used as an index of particle concentration. Assuming fairly regular shape and refractive index of the particles, a pulse height analyzer can estimate the size of each particle as it passes through the

light. Thus, a curve of the particle size against number can be generated with the more sophisticated versions of this type of instrument.

More recent devices use lasers rather than noncoherent light sources, but the principle is generally the same. Scattering of light at a 90-degree angle by particles in the aerosol is used to enumerate and size the particles. The range of particles detectable by laser instruments exceeds the range of noncoherent, polychromatic light-scattering photometers. Some more sophisticated devices display specific size fractions (respirable, thoracic, inhalable dust, PM 10, PM 2.5, PM 1.0), detect only fibers, interface with computers and perform data logging, time-weighted average calculations, and may be alarmed.

In general, these instruments should not typically be considered as a substitute for traditional sampling, but as a surrogate, especially useful when sampling nuisance dusts or well characterized dust or when monitoring for time varying levels of dusts to detect peaks or point sources. They can be particularly useful in detecting leaks from lead or asbestos abatement work containments. Used properly, they greatly enhance the industrial hygienist's ability to monitor particle exposure. Personal sampling versions are available, but they cannot discriminate among different chemical types of dust in a mixed dust aerosol. Recently, very large stationary equipment that counts, sizes, and chemically analyzes PM has been developed for environmental testing. In time, this type of equipment may become available to the industrial hygiene community.

A few gravimetric real time particle detectors are available. One is a modified multistage cascade impactor, with each stage, starting from the top, collecting a smaller and smaller average AED particle size. Each stage is equipped with a piezoelectric balance, and the change in weight on each stage is recorded and displayed constantly.

Historically, other direct-reading devices have operated by electrostatic deposition of dust onto a piezoelectric sensor, the resonant frequency of the sensor being the dependent variable which changes as the dust loading changes. Other devices used the attenuation of beta particles through an impaction membrane to provide an indication of dust accumulation. As more dust accumulated, the ability of beta particles to pass through the membrane and dust cake declined in direct proportion to the deposited dust. Konimeters were used to deposit dust on the surface of a sticky slide, which was then examined in the field through a built-in microscope.

BIOLOGICAL MONITORING FOR INDIVIDUALS EXPOSED TO PARTICULATE MATTER

Another tool in the industrial hygiene arsenal to assess occupational exposures to PM is biological monitoring. Biological monitoring gives an index of absorbed dose, whether by inhalation, percutaneous absorption, or ingestion. The *determinant* in biological monitoring can be the chemical itself or one of its metabolites (in urine, blood, or expired air), or a reversible biochemical change in the body indicative of a biological response to the exposure. Depending on the determinant, specimen, and time of sampling, biological monitoring may be representative of the intensity of recent exposure, an average daily exposure, or chronic cumulative exposure.

Tests that can detect permanent physiological impairment or disease are not usually classified under the category of biological monitoring, but rather fall under the broader heading of *medical surveillance*.

OSHA has promulgated a number of expanded standards for PM, which include requirements for biological monitoring, including lead, arsenic, and cadmium. The lead biological monitoring procedure is particularly interesting, as it evaluates both the level of lead in the blood as a primary determinant, and the body's response to the lead in the blood in terms of the formation of zinc protoporphyrin. Both of these are usually used as indicators of long term chronic exposure.

The ACGIH has published a list of Biological Exposure Indices® (BEIs®), which are widely used as guidelines in assessing employees' exposure and response to occupational stressors. There are a number of BEIs for PM. Some of these are shown in Table 8–L.

Although still largely limited to Department of Energy owned or operated sites, a very unusual blood test for beryllium will probably spread rapidly to other sites where beryllium and insoluble beryllium compounds are used. This test, called the Beryllium Lymphocyte Proliferation Test (BLPT) helps to identify workers who have become sensitized to beryllium. To develop chronic beryllium disease an individual must first become sensitized. Not all sensitized employees will go on to develop any level of disease, but many will eventually develop granulomas in the lungs detectable by bronchoscopy or sensitive ergospirometry. A subset of these employees who develop medically detectable chronic beryllium disease (CBD) will, over time, develop clinical illness—shortness of breath upon exertion, chest tightness, and chest pain which may progress to debilitating or even fatal illness. Beryllium exposure also seems to increase the risk of developing lung cancer.

Unlike in many other lung diseases classically termed *pneumoconioses*, the macrophage probably plays a relatively small role in CBD, that of presenting the beryllium, bound as a hapten to some other biological molecule, to a T lymphocyte, probably of the T4 subtype. Unlike asbestosis and silicosis, where much of the lung damage is caused by the resident macrophages, the T4 memory lymphocytes appear to sustain the immunological process that leads to CBD.

NIOSH has recommended many other biological monitoring and medical surveillance protocols for individuals exposed to PM, such as platinum in urine or blood, pen-

Table 8–L. ***Biological Monitoring For Personnel Exposed to Selected Particulate Matter***

Agent	*Determinant*	*Sampling Time*
Arsenic and inorganic compounds	Inorganic arsenic and methylated metabolites in urine	End of workweek
Cadmium and inorganic compounds	Cadmium in urine Cadmium in blood	Not critical Not critical
Chromium VI+, water soluble fume	Total Cr in urine	Before and after shift End of workweek
Cobalt	Cobalt in urine or Cobalt in blood	End of workweek
Fluorides	Fluorides in urine	Before and after shift
Lead	Lead in blood	Not critical
Organophosphorous which may inhibit cholinesterase	Cholinesterase activity in red blood cells	Discretionary
Parathion	Total p-nitrophenol in urine Cholinesterase in red blood cells	End of shift Discretionary
Pentachlorophenol	Total PCP in urine Free PCP in plasma	Prior to last shift in week End of a shift
Vanadium Pentoxide	Vanadium in urine	End of workweek

tachlorophenol metabolites in blood, and reduced immunological competence after exposure to 4-aminodiphenyl.

SUMMARY

Particulate matter is usually an occupational hazard when suspended in air to form an aerosol. However, there are exceptions to this, and skin exposure or ingestion can be significant routes of exposure in some occupational settings. Exposure to particulate matter is assessed primarily by air sampling, although often with special reference to equivalent aerodynamic subfractions of the particle cloud.

Adjuncts to air sampling include surface sampling, skin or clothing sampling, biological sampling, and medical surveillance. While many aspects of an aerosol control program are stipulated in OSHA regulations, many other features are provided only in guidance form by the ACGIH, NIOSH, or other consensus organization.

The hazard posed by a cloud of particulate matter depends on a variety of factors, including its chemical composition, crystalline structure, isotope, solubility, shape, concurrent exposures, and particle size. It is often necessary to consider two or more of these factors when sampling for a particular agent.

Many industrial hygiene sampling and analytical methods are burdened with imprecision, inaccuracy, biases, and other technical problems that the industrial hygienist must understand to place the results in proper perspective.

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Chapter 9

Industrial Noise

by John J. Standard, MS, MPH, CIH, CSP

The sounds of industry, growing in volume over the years, have heralded not only technical and economic progress, but also an ever-increasing incidence of hearing loss and other noise-related hazards to exposed employees. Noise is not a new hazard. Indeed, noise-induced hearing loss was observed centuries ago. In 1700, Ramazzini in "De Morbis Artificium Diatriba" described how workers who hammer copper "have their ears so injured by that perpetual din . . . that workers of this class become hard of hearing, and if they grow old at this work, completely deaf." Before the Industrial Revolution, however, comparatively few people were exposed to high levels of noise in the workplace. The advent of steam power during the Industrial Revolution first brought general attention to noise as an occupational hazard. Workers who fabricated steam boilers were found to develop hearing loss in such numbers that the malady was dubbed boilermakers' disease. The increasing mechanization that has occurred in all industries and in most trades has since aggravated the noise problem. Noise levels in the workplace, particularly those maintained in mechanized industries, are likely to be more intense and sustained than any noise levels experienced outside the workplace.

The recognition, evaluation, and control of industrial noise hazards are introduced in this chapter. Basically, this involves assessing the extent of the noise problem, setting objectives for a noise abatement program, controlling exposure to excessive noise, and monitoring the hearing of exposed employees.

COMPENSATION ASPECTS

The trend toward covering hearing losses under state workers' compensation laws has stimulated interest on the part of employers in controlling industrial noise exposures. Compensation laws that cover loss of hearing due to noise exposure have been enacted in many states; compensation is being awarded in other states even though

hearing loss is not specifically defined in many compensation laws.

Occupational hearing loss can be defined as a hearing impairment of one or both ears, partial or complete, that results from one's employment. It includes acoustic trauma as well as noise-induced hearing loss.

Acoustic trauma denotes injury to the sensorineural elements of the inner ear. Acoustic trauma is produced by one or a few exposures to sudden intense acoustic forms of energy resulting from blasts and explosions or by direct trauma to the head or ear. The worker should be able to relate the onset of hearing loss to one single incident. For details on ear anatomy, see Chapter 4, The Ears.

Noise-induced hearing loss, on the other hand, describes the cumulative permanent loss of hearing—always of the sensorineural type—that develops over months or years of hazardous noise exposure.

Noise-induced hearing loss usually affects both ears equally in the extent and degree of loss. It should also be kept in mind that the onset of hearing loss, its progression, its permanency, and the characteristics of the audiograms obtained, vary depending on whether the injury is a noise-induced hearing loss or acoustic trauma.

To establish a diagnosis of noise-induced hearing loss and a causal relationship to employment, the physician considers the following factors:

- The employee's history of hearing loss—onset and progress
- The employee's occupational history, type of work, and years of employment
- The results of the employee's otological examination
- The results of audiological and hearing studies performed (preplacement, periodic, and termination)
- The ruling out of nonindustrial causes of hearing loss

It has been estimated that 1.7 million workers in the United States between 50 and 59 years of age have compensable noise-induced hearing loss. Assuming that only 10 percent of these workers file for compensation and that the average claim amounts to $3,000, the potential cost to industry could exceed $500 million.

Estimates show that 16.9 percent of the working population are employed in jobs where the noise level exceeds 85 dBA (Table 9–A).

At present, no test can predict which individuals will incur a hearing loss. If enough people are placed in an environment where the predominant noise level exceeds 85 dBA for a sufficient period of time, some individuals incur a hearing impairment greater than that due to presbycusis (loss of hearing due to aging). The number of workers subjected to noise hazards exceeds that of those exposed to any other significant occupational hazard.

The audiometer provides an easily reproducible means of measuring the status of an individual's hearing with appreciable accuracy. Partial hearing losses are easily measurable by commercially available audiometers.

PROPERTIES OF SOUND

Sound can be defined as any pressure variation (in air, water, or some other medium) that the human ear can detect.

Sound produces a sensory response in the brain. The perception of sound resulting in the sensation called hearing is the principal sensory response; however, under certain conditions, additional subjective sensations ranging from pressure in the chest cavity to actual pain in the ears can be produced (see Chapter 4, The Ears). There are certain effects produced by sounds that appear to be universally undesirable for all people. These effects include the following:

- The masking of wanted sounds, particularly speech
- Auditory fatigue
- Damage to hearing
- Annoyance

Noise

What we call noise is usually sound that bears no information and whose intensity usually varies randomly in time. The word *noise* is often used to mean unpleasant sound that the listener does not want to hear. Noise interferes with the perception of wanted sound and is likely to be physiologically harmful.

Noise does not always have particular physical characteristics that distinguish it from wanted sound. No instrument can distinguish between a sound and a noise—only human reaction can.

A variety of methods have been devised to relate objective physical measurements of sound to subjective human perception. The purpose of this section is to outline both the objective physical properties of sound and its important subjective aspects.

The term *sound* usually refers to the form of energy that produces a sensation perceived by the sense of hearing in humans, whereas *vibration* usually refers to nonaudible acoustic phenomena that are recognized by the tactile experience of touch, or feeling. However, there is no essential physical difference between the sonic and vibratory forms of sound energy.

The generation and propagation of sound are easily visualized by means of a simple model. Consider a plate suspended in midair (Figure 9–1). When struck, the plate vibrates rapidly back and forth. As the plate travels in either direction, it compresses the air, causing a slight increase in its pressure. When the plate reverses direction, it leaves a partial vacuum, or rarefaction, of the air. These alternate compressions and rarefactions cause small but repeated fluctuations in the atmospheric pressure that extend outward from the plate. When these pressure variations strike an eardrum, they cause it to vibrate in response to the slight changes in atmospheric pressure. The disturbance of the eardrum is translated into a neural sensation in the inner ear and is carried to the brain, where it is interpreted as sound (Figure 9–2).

Sound is invariably produced by vibratory motion of some sort. The sounding body must act on some medium to pro-

Table 9–A. *Estimated Number of Workers Exposed to Noise at or Above 85 dBA, by Economic Sector (two-digit SIC)**

Economic Sector	SIC	Total No. Production Workers	No.	As % of Total Production Workers
Agriculture, forestry, and fishing:				
Agriculture services	07	89,189	17,618	19.8
Mining:				
Oil and gas extraction	13	330,841	76,525	23.1
Construction:				
General bldg. contractors	15	664,833	105,299	15.8
Heavy construction, except building	16	517,969	124,610	24.0
Special trade contractors	17	1,228,744	191,087	15.6
Manufacturing:				
Food and kindred products	20	1,188,267	343,030	28.9
Tobacco products	21	106,399	57,764	54.3
Textile mill products	22	615,322	262,108	42.6
Apparel and other finished products	23	1,082,236	150,824	13.9
Lumber and wood products	24	475,730	196,489	41.3
Furniture and fixtures	25	428,539	121,271	28.3
Paper and allied products	26	488,101	164,808	33.8
Printing and publishing	27	724,707	154,862	21.4
Chemicals and allied products	28	592,059	102,671	17.3
Petroleum and coal products	29	160,516	31,998	19.9
Rubber and misc. plastics products	30	595,525	135,611	22.8
Leather and leather products	31	144,200	9,346	6.5
Stone, clay, and glass products	32	457,983	98,215	21.5
Primary metal industries	33	824,725	269,270	32.7
Fabricated metal products	34	1,151,777	336,919	29.3
Industrial machinery and equipment	35	1,544,883	229,509	14.9
Electronic and other electric equipment	36	1,287,842	104,553	8.1
Transportation equipment	37	1,311,750	238,609	18.2
Instruments and related products	38	555,108	48,014	8.7
Miscellaneous mfg. industries	39	418,805	39,307	9.4
Transportation and public utilities:				
Local and interurban passenger transit	41	171,428	14,832	8.7
Trucking and warehousing	42	561,058	39,150	7.0
Transportation by air	45	312,931	94,656	30.3
Communications	48	387,505	23,124	6.0
Electric, gas, and sanitary services	49	588,041	89,730	15.3
Wholesale trade:				
Wholesale trade—durable goods	50	528,659	110,283	20.9
Wholesale trade—nondurable goods	51	99,410	5,287	5.3
Retail trade:				
Automotive, dealers and service stations	55	334,063	4,543	1.4
Services:				
Personal services	72	366,545	33,462	9.1
Business services	73	766,108	11,246	1.5
Auto repair, services, and parking	75	320,459	33,997	10.6
Misc. repair services	76	143,302	12,682	8.9
Health services	80	2,679,610	15,677	0.6
Total		**24,245,169**	**4,098,986**	**16.9**

* SIC=Standard industrial classification. Source: OMB (1987).

Reprinted from NIOSH Criteria Document, *Occupational Noise Exposure – Revised Criteria,* 1998. Cincinnati: NIOSH, 1998.

Based on data collected by NOES (NIOSH 1988a,b, 1990). Not all two-digit SIC sectors and not all four-digit SIC industries within each two-digit SIC sector were surveyed. The NOES covered 39 of 83 two-digit SIC sectors, and the NOES estimates were representative of only the four-digit SIC industries actually surveyed. For example, within agricultural services (SIC 07), the estimates are for crop preparation services (SIC 0723), veterinary services for animal specialties (SIC 0742), lawn and garden services (SIC 0782), and ornamental shrub and tree services (SIC 0783) only, because no surveys were done for soil preparation services (SIC 0711), crop planting and protecting (SIC 0721), crop harvesting (SIC 0722), cotton ginning (SIC 0724), veterinary services for livestock (SIC 0741), livestock services (SIC 0751), animal specialty services (SIC 0752), farm labor contractors (SIC 0761), farm management services (SIC 0762), and landscape counseling and planning (SIC 0781).

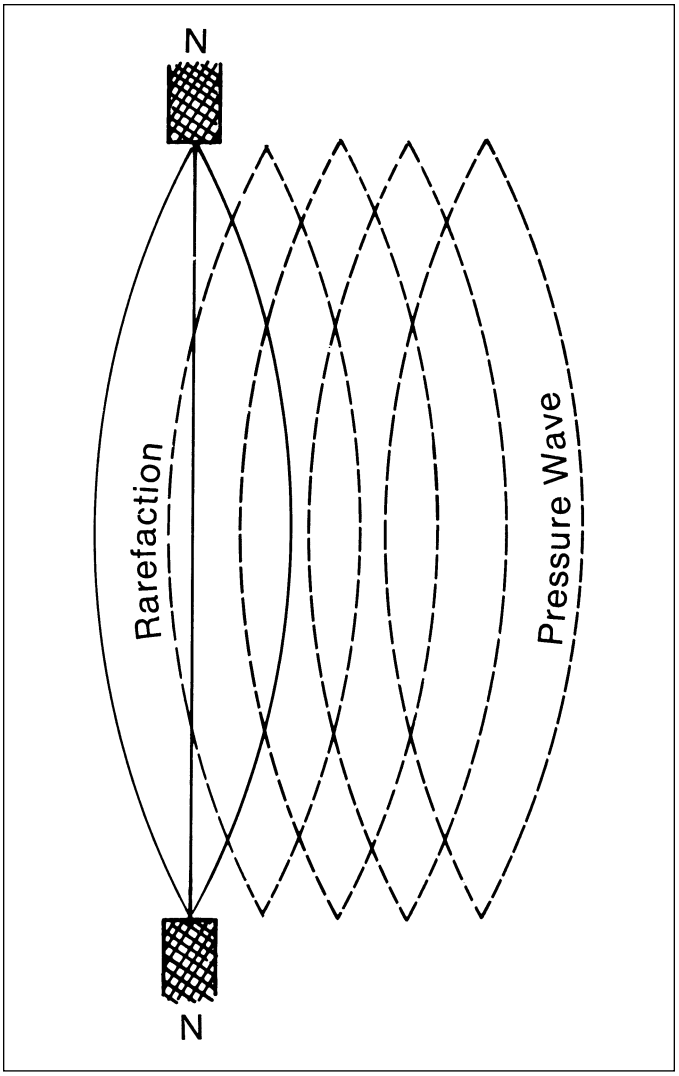


Figure 9–1. As the vibrating plate moves back and forth, it compresses the air in the direction of its motions. When it reverses direction, it produces a partial vacuum, or rarefaction, imparting energy to the air, which radiates away from the plate as sound.

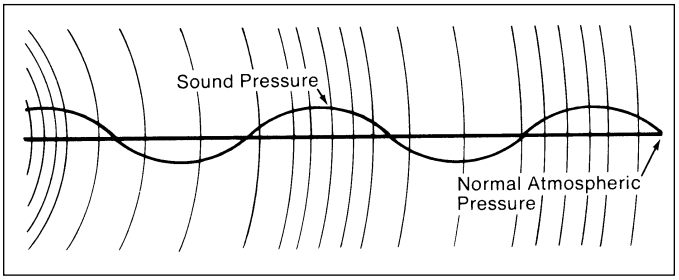


Figure 9–2. Air is an elastic medium and behaves as if it were a succession of adjoining particles. The resulting motion of the medium is known as wave motion, and the instantaneous form of the disturbance is called a sound wave.

duce vibrations that are characteristic of sound. Any type of vibration can be a source of sound, but by definition, only longitudinal vibration of the conducting medium is a sound wave.

Sound Waves

Sound waves are a particular form of a general class of waves known as elastic waves. Sound waves can occur in any elastic medium such as air, water, or steel. One sound wave may have three times the frequency and one-third the intensity (amplitude) of another sound wave. However, if both the waves cross their respective zero positions in the same direction at the same time, they are said to be in phase (Figure 9–3).

Frequency

Using sound propagating through air as an example, *frequency* is the number of times per second that an air molecule at the sound source is displaced from its position of equilibrium, rebounds through the equilibrium position to a maximum displacement opposite in direction to the initial displacement, and then returns to its equilibrium position. In other words, frequency is the number of times per second a vibrating body traces one complete cycle of motion (Figure 9–4). The time required for each cycle is known as the period of the wave and is simply the reciprocal of the frequency. The phrase formerly used to describe frequency, cycles per second, has now been replaced by *Hertz,* abbreviated *Hz.*

Frequency is perceived as pitch. The audible range of frequencies for humans with good hearing is between 20 Hz and 20,000 Hz. Most everyday sounds contain a mix-

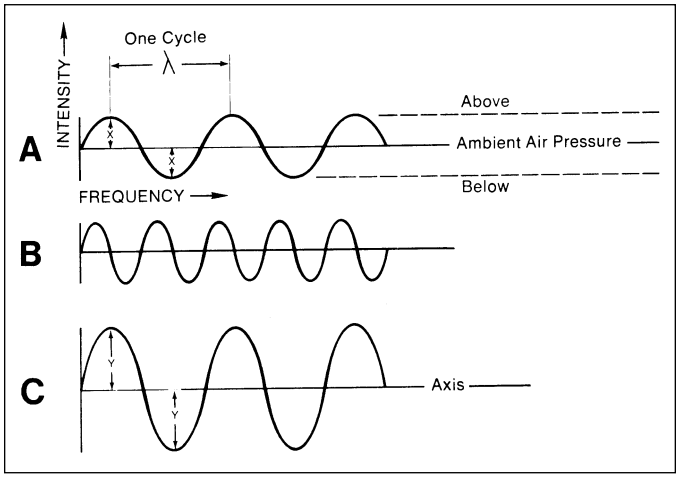


Figure 9–3. The curves shown are pictorial representations of sound waves. Pitch is related to frequency and loudness is related to the intensity of a sound. Curve B represents a sound that has a higher frequency—a higher perceived pitch—than the sound represented by curve A because the variations in air pressure, as represented by a point on the curve, cross the axis more often. The intensity of a sound can be shown by the height of the curve. Curve C represents a sound that has a greater intensity—a greater perceived loudness—than the sound represented by curve A (distance Y is greater than distance X).

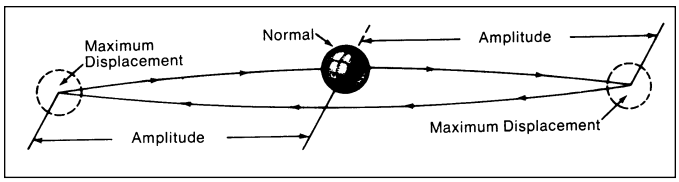


Figure 9–4. Relative positions of an air molecule during one complete cycle of motion.

ture of frequencies generated by a variety of sources. A sound's frequency composition is called its spectrum. The frequency spectrum can be a determining factor in the level of annoyance caused by noise; high-frequency noise generally is more annoying than low-frequency noise. Also, narrow frequency bands or pure tones (single frequencies) can be somewhat more harmful to hearing than broadband noise.

Wavelength

Wavelength is the distance measured between two analogous points on two successive parts of a wave. In other words, wavelength is the distance that a sound wave travels in one cycle. The Greek letter lambda (λ) is used to express wavelength, and it is measured in feet or meters (Figure 9–3).

Wavelength is an important property of sound. For example, sound waves that have a wavelength that is much larger than an obstacle are little affected by the presence of that obstacle; the sound waves bend around it. This bending of the sound around obstacles is called *diffraction*.

If the wavelength of the sound is small in comparison with the size of an obstacle (small wavelengths are characteristic of high-frequency sounds), the sound is reflected or scattered in many directions, and the obstacle casts a "shadow." Actually, some sound is diffracted into the shadow, and there is significant reflection of the sound. As a consequence of diffraction, a wall is of little use as a shield against low-frequency sound (long wavelength), but it can be an effective barrier against high-frequency sound (short wavelength) (Figure 9–5).

Velocity

The velocity at which the analogous pressure points on successive parts of a sound wave pass a given point is called the speed of sound. The speed of sound is always equal to the product of the wavelength and the frequency:

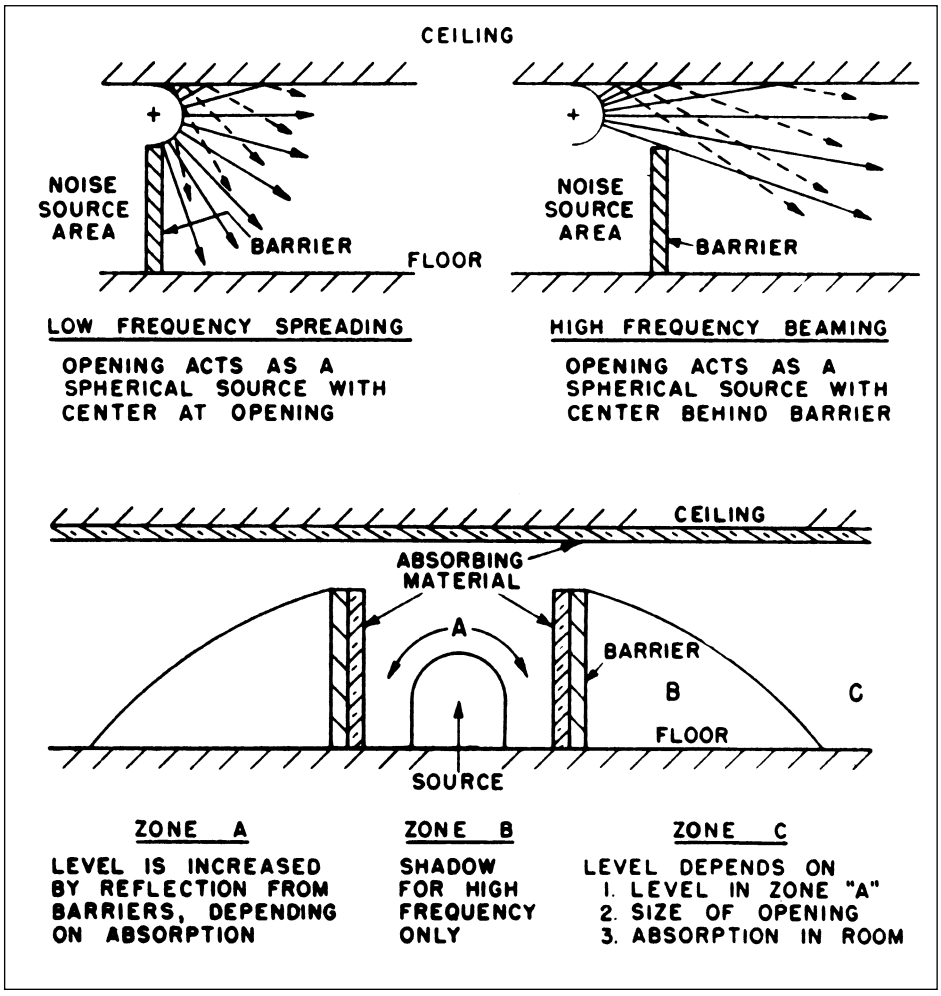


Figure 9–5. The effects of a barrier as a shield to contain noise of low or high frequency.

$$c = f\lambda \quad (1)$$

where c = speed of sound (feet or meters per second)
f = frequency of sound (Hz)
λ = wavelength (feet or meters)

The speed with which the sound disturbance spreads depends on the mass and elastic properties of the medium. In air at 72 F, the speed of sound is about 1,130 ft/sec (344 m/sec). Its effects are commonly observed in echoes and in the apparent delay between a flash of lightning and the accompanying thunder.

In a homogeneous medium, the speed of sound is independent of frequency; that is, in such a medium, sounds of all frequencies travel at the same speed. However, the speed of sound varies with the density and compressibility of the medium through which it is traveling. Speed increases as medium density increases and medium compressibility decreases. For example, the speed of sound is approximately 1,433 m/sec in water, 3,962 m/sec in wood, and 5,029 m/sec in steel. Sound, therefore, can be transmitted through many media before it is eventually transmitted through air to the ear of the receiver.

Sound Pressure

Sound is a slight, rapid variation in atmospheric pressure, caused by some disturbance or agitation of the air. The sounds of normal conversation amount to sound pressure of only a few millionths of a pound per square inch, yet they can be easily heard because of the remarkable sensitivity of the human ear. The sounds that can damage our hearing have sound pressures of only a few thousandths of a pound per square inch.

Most common sounds consist of a rapid, irregular series of positive pressure disturbances (compressions) and negative pressure disturbances (rarefactions) measured against the equilibrium pressure value. If we were to measure the mean value of a sound pressure disturbance, we would find it to be zero because there are as many positive compressions as negative rarefactions. Thus, the mean value of sound pressure is not a useful measurement. We must look for a measurement that permits the effects of rarefactions to be added to (rather than subtracted from) the effects of compressions.

The *root-mean-square (rms) sound pressure* is one such measurement. The rms sound pressure is obtained by squaring the value of the sound pressure disturbance at each instant of time. The squared values are then added and averaged over the given time. The rms sound pressure is the square root of this time average. Because the squaring operation converts all the negative sound pressures to positive squared values, the rms sound pressure is a useful, nonzero measurement of the magnitude of the sound wave. The units used to measure sound pressure are micropascals (μPa), newtons per square meter (N/m^2), microbars (μbar), and dynes per square centimeter (d/cm^2). Relations among these units are as follows: 1 Pa = 1 N/m^2 = 10 μbar = 10 d/cm^2.

Decibels and Levels

Even though the weakest sound pressure perceived as sound is a small quantity, the range of sound pressure perceived as sound is extremely large. The weakest sound that can be heard by a person with very good hearing in an extremely quiet location is known as the *threshold of hearing*. At a reference tone of 1,000 Hz, the threshold of hearing for an average person is taken to be a sound pressure of 20 μPa. The *threshold of pain,* or the greatest sound pressure that can be perceived without pain, is approximately 10 million times greater. It is therefore more convenient to use a *relative scale* of sound pressure rather than an absolute scale.

For this purpose, the bel, a unit of measure in electrical-communications engineering, is used. The decibel, abbreviated dB, is the preferred unit for measuring sound. One decibel is one-tenth of a bel and is the minimum difference in loudness that is usually perceptible. By definition, the decibel is a dimensionless unit used to express the logarithm of the ratio of a measured quantity to a reference quantity. In acoustics, the decibel is used to describe the level of quantities that are proportional to sound power.

Sound power (W) is the amount of energy per unit time that radiates from a source in the form of an acoustic wave. *Sound power level* (L_W), which is expressed in decibels relative to the reference power of 10^{-12} watt (W_0), expresses the total amount of sound power radiated by a sound source, regardless of the space into which the source is placed. The relationship is shown below.

$$L_W = 10 \log \frac{W}{W_0} \quad (2)$$

where W = sound power (watts)
W_0 = reference power (10^{-12} watts)
log = a logarithm to the base 10

Consider for example, a large chipping hammer having a sound power of 1 watt. Expressing this sound power in decibels,

$$L_W = 10 \log \frac{W}{W_0} = 10 \log \frac{1}{10^{-12}} = 10 \log 10^{12} = 120 \text{ dB} \quad (3)$$

As sound power is radiated from a point source in free space, the power is distributed over a spherical surface, so that at any given point there exists a certain sound power per unit area. This is designated as intensity and is measured in units of watts per square meter. Although intensity diminishes as distance from the source increases, the power that is radiated, being the product of the intensity and the area over which it is spread, remains constant.

Sound power cannot be measured directly. It is possible to measure intensity, but the instruments are expensive and must be used carefully. Under most conditions of sound

radiation, sound intensity is proportional to the square of sound pressure. Sound pressure can be measured more easily, so sound level meters are built to measure *sound pressure level* (L_p) in decibels.

The sound level meter directly indicates sound pressure level referenced to a sound pressure of 20 μPa, the approximate threshold of hearing. The equation for sound pressure level is:

$$L_p = 10 \log \frac{p^2}{p_0^2} = 20 \log \frac{p}{p_0} \quad (4)$$

where p = measured root-mean-square (rms) sound pressure
p_0 = reference rms sound pressure (20 μPa)

Note that the multiplier is 20 and not 10 as in the case of the sound power level equation. This is because sound power is proportional to the square of sound pressure and because $10 \log p^2 = 20 \log p$.

Table 9–B shows the relationship between sound pressure in micropascals and sound pressure level in decibels for some common sounds. The table also illustrates the advantage of using decibel notation rather than the wide range of pressure (or power). Note that a change of sound pressure by a factor of 10 corresponds to a change in sound pressure level of 20 dB. Also note that any range over which the sound pressure is doubled is equivalent to 6 dB whether at low or high levels. For example, sound pressures of 20 μPa and 40 μPa are equivalent to the following sound pressure levels:

$p = 20\mu Pa$:

$$L_p = 20 \log \frac{p}{p_0} = 20 \log \frac{20}{20} = 20 \log 1 = 0 \text{ dB} \quad (5)$$

$p = 40\mu Pa$:

$$L_p = 20 \log \frac{p}{p_0} = 20 \log \frac{40}{20} = 20 \log 2 = 6 \text{ dB} \quad (6)$$

Although a doubling of sound pressure represents an increase of 6 dB in the sound pressure level, doubling the *sound power* results in an increase of 3 dB in the sound power level:

$$W = 1 \text{ watt: } L_W = 10 \log \frac{1}{10^{-12}} = 120 \text{ dB} \quad (7)$$

$$W = 2 \text{ watt: } L_W = 10 \log \frac{2}{10^{-12}} = 123 \text{ dB} \quad (8)$$

Again, as seen in the above examples, doubling the sound power increases the sound power level 3 dB, whereas doubling the sound pressure increases the sound pressure level 6 dB. These results are not contradictory because doubling the sound power is equivalent to doubling the *square* of the sound pressure. Remember, sound power is proportional to the *square* of sound pressure.

Table 9–B. ***Sound Pressure and Sound Pressure Level Values for Some Typical Sounds***

Sound Pressure (μPa)	*Overall Sound Pressure Level (dB, re: 20 μPa)*	*Example*
20	0	Threshold of hearing
63	10	
200	20	Studio for sound pictures
630	30	Soft whisper (5 feet)
2,000	40	Quiet office; audiometric testing booth
6,300	50	Average residence; large office
20,000	60	Conversational speech (3 ft)
63,000	70	Freight train (100 ft)
200,000	80	Very noisy restaurant
630,000	90	Subway; printing press plant
2,000,000	100	Looms in textile mill; electric furnace area
6,300,000	110	Woodworking; casting shakeout area
20,000,000	120	Hydraulic press; 50-hp siren (100 ft)
200,000,000	140	Threshold of pain; jet plane
20,000,000,000	180	Rocket-launching pad

* A change of sound pressure by a factor of 10 corresponds to a change in sound pressure level of 20 dB.

There is a common tendency to confuse sound power with sound pressure. Sound power and sound pressure can be illustrated simply with an analogy between light and sound.

Light bulbs are rated in terms of their power consumption (60-W bulbs, 25-W bulbs, etc.). From experience, we know that, in a given location, the intensity or illumination of a 60-W bulb is greater than that of a 25-W bulb at a given distance. Analogously, a sound source of 60 W produces a greater sound pressure level than a 25-W source at a given distance.

Sound power is somewhat analogous to the power rating of the light bulb. A "weak" sound source would produce low sound levels, whereas a "stronger" sound source would produce higher sound levels. Sound power level is independent of the environmental surroundings. Sound pressure, on the other hand, is related to intensity and is analogous to the illumination produced by the light bulb. The magnitude of the sound pressure from a given sound source depends on the distance from the source. As discussed earlier, sound pressure is readily measured by a sound level meter, but sound power cannot be measured directly.

It is important to note that the decibel scale of measurement is not used only in the description of sound pressure level and sound power level. By definition, the decibel is

a dimensionless unit related to the logarithm of the ratio of a measured quantity to a reference quantity. The decibel has no meaning unless a reference quantity is specified. Because of the mathematical properties of the logarithmic function, the decibel scale can compress data involving entities of large and small magnitude into a relative scale involving a small range of numbers. The decibel is commonly used to describe levels of such things as acoustic intensity, hearing thresholds, electrical voltage, electrical current, and electrical power, as well as sound pressure and sound power.

Because decibels are logarithmic values, it is not proper to add them by normal algebraic addition. For example, 60 dB plus 60 dB *does not* equal 120 dB but only 63 dB.

In order to show how to combine decibel levels of sound sources, we present some examples.

Example 1

Two sources are radiating noise in a free field. One source has a sound power level of 123 dB and the other source has a sound power level of 117 dB (re: 10^{-12} W). What is the combined sound power level of these two sources?

Solution:

$$L_W = 10 \log \frac{W}{W_0} \tag{9}$$

or

$$\frac{W}{W_0} = 10^{L_W/10} \tag{10}$$

$$\frac{W_1}{W_0} = 10^{L_{W_1}/10} = 10^{123/10} = 10^{12.3} = 1.995 \times 10^{12} \tag{11}$$

$$\frac{W_2}{W_0} = 10^{L_{W_2}/10} = 10^{117/10} = 10^{11.7} = 5.012 \times 10^{11} \tag{12}$$

$$\frac{W_1}{W_0} + \frac{W_2}{W_0} = 2.496 \times 10^{12} \tag{13}$$

The combined sound power level of the two sources, L_W (total), can then be calculated as

$$\begin{aligned} L_W\,(\text{total}) &= 10 \log\left(\frac{W_1}{W_0} + \frac{W_2}{W_0}\right) \\ &= 10 \log\,(2.496 \times 10^{12}) \\ &= 10\,(12.40) \\ L_W\,(\text{total}) &= 124 \text{ dB} \end{aligned} \tag{14}$$

The same process can be used for sound pressure levels.

Example 2

Suppose the sound pressure level of each of three individual noise sources is measured at a point such that with only the first source running, the Lp = 86 dB, with only the second source running it is 84 dB, and with only the third source running it is 89 dB (re: 20 μPa). What will the sound pressure level at the point be with all three sources running concurrently?

$$L_p = 10 \log\left(\frac{p}{p_0}\right)^2 \tag{15}$$

or

$$\left(\frac{p}{p_0}\right)^2 = 10^{L_p/10} \tag{16}$$

$$\begin{aligned} \left(\frac{p_{\text{total}}}{p_0}\right)^2 &= 10^{L_{p_1}/10} + 10^{L_{p_2}/10} + 10^{L_{p_3}/10} \\ &= 10^{8.6} + 10^{8.4} + 10^{8.9} \\ &= (3.982 + 2.512 + 7.944)\,10^8 \\ \left(\frac{p_{\text{total}}}{p_0}\right)^2 &= 14.438 \times 10^8 \end{aligned} \tag{17}$$

The sound pressure level at the point with all three sources running is then equal to

$$\begin{aligned} L_p\,(\text{total}) &= 10 \log\left(\frac{p_{\text{total}}}{p_0}\right)^2 \\ &= 10 \log\,(14.438 \times 10^8) \\ &= 10\,(9.16) \\ L_p\,(\text{total}) &= 91.6 \text{ dB} \end{aligned} \tag{18}$$

In general then, the procedure for adding decibels can be summarized as follows:

$$L_{\text{total}} = 10 \log\left(\sum_{i=1}^{N} 10^{L_i/10}\right) \tag{19}$$

where L can be sound power level or sound pressure level.

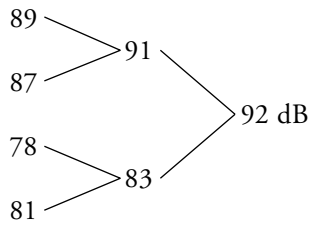
It is often adequate to use the simplified schedule shown below for adding decibels.

Difference in Decibel Values	*Add to Higher Value*
0 or 1 dB	3 db
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

Examples:
83 dB + 82 dB = 86 dB
83 dB + 80 dB = 85 dB
83 dB + 78 dB = 84 dB
83 dB + 73 dB = 83 dB

More than two levels can be combined using the above simplified schedule by taking the combinations in pairs.

Example 3
When measured at the same location, four noise sources have sound pressure levels of 89, 87, 78, and 81 dB, respectively. What would the sound pressure level at this location be if all four sources were running concurrently? Using the simplified method,



Using the calculated method,

$$L_p = 10 \log (10^{8.9} + 10^{8.7} + 10^{7.8} + 10^{8.1}) = 91.7 \text{ dB} \quad (20)$$

Although the simplified method is less accurate than the calculated method, the difference may not be significant. Even so, when accurate results are required, the calculated method should be used.

Loudness

Although loudness depends primarily on sound pressure, it is also affected by frequency. (Pitch is closely related to frequency.) The reason for this is that the human ear is more sensitive to high-frequency sounds than it is to low-frequency sounds.

The upper limit of frequency at which airborne sounds can be heard depends primarily on the condition of a person's hearing and on the intensity of the sound. For young adults, this upper limit is usually somewhere between 16,000 and 20,000 Hz. For most practical purposes, the actual figure is not important. It is important, however, to realize that most people lose sensitivity for the higher-frequency sounds as they grow older (presbycusis).

The complete hearing process seems to consist of a number of separate processes that, in themselves, are fairly complicated. No simple relationship exists between the physical measurement of a sound pressure level and the human perception of the sound. One pure tone may sound louder than another pure tone, even though the measured sound pressure level is the same in both cases.

Sound pressure levels, therefore, are only a part of the story and can be deceiving. The fundamental problem is that the quantities to be measured must include a person's reaction to the sound—a reaction that can be determined by such varied factors as the state of the person's health, characteristics of the sound, and the person's attitude toward the device or the person that generates the sound. In the course of time, various loudness level–rating methods have been suggested, and a number of different criteria for tolerable noise levels have been proposed.

A complete physical description of sound must include its frequency spectrum, its overall sound pressure level, and the variation of both of these quantities over time. *Loudness* is the subjective human response to sound pressure and intensity. At any given frequency, loudness varies directly as sound pressure and intensity vary, but not in a simple, straight-line manner.

The physical characteristics of a sound as measured by an instrument and the "noisiness" of a sound as a subjective characteristic may bear little relationship to one another. A sound level meter cannot distinguish between a pleasant sound and an unpleasant one. A human reaction is required to differentiate between a pleasant sound and a noise. Loudness is not merely a question of sound pressure level. A sound that has a constant sound pressure can be made to appear quieter or louder by changing its frequency.

EQUAL-LOUDNESS CONTOURS

Results of experiments designed to determine the response of the human ear to sound were reported by Fletcher and Munson in 1933. A reference tone and a test tone were presented alternately to the test subjects (young men), who were asked to adjust the level of the test tone until it sounded as loud to them as the reference tone (1,000 Hz). The results of these experiments yielded the familiar Fletcher–Munson, or equal-loudness, contours (Figure 9–6). The contours represent the sound pressure level necessary at each frequency to produce the same loudness response in the average listener. The nonlinearity of the ear's response is represented by the changing contour shapes as the sound pressure level is increased, a phenomenon that is particularly noticeable at low frequencies. The lower, dashed, curve indicates the threshold of hearing, which represents the sound pressure level necessary to trigger the sensation of hearing in the average listener. The actual threshold varies as much as ±10 dB among healthy individuals.

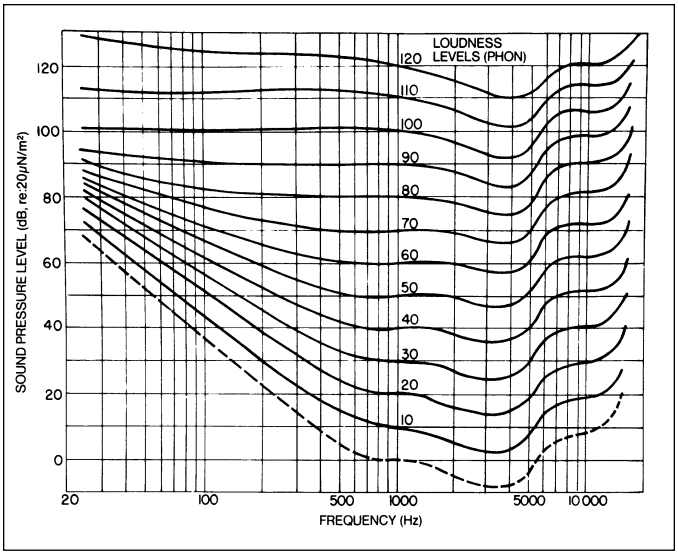


Figure 9–6. Free-field equal-loudness contours of pure tones. Because the human ear is more sensitive to the higher frequencies of sound, changing the frequency of a sound changes its relative loudness. These are also called Fletcher–Munson contours. (Adapted from the *Handbook of Noise Measurement,* 9th ed. GenRad, Inc., 1980.)

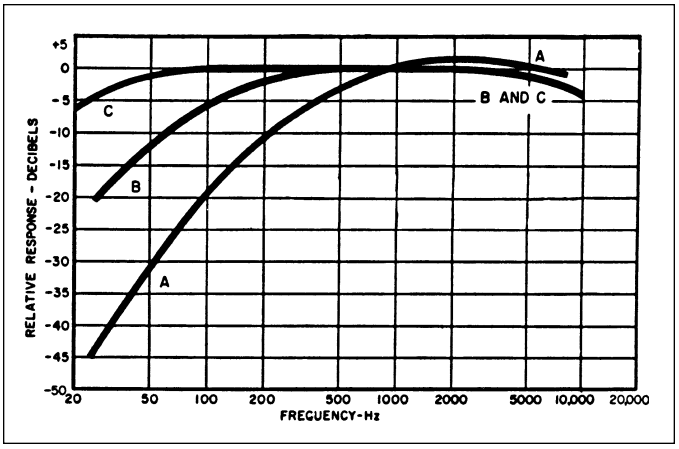


Figure 9–7. Frequency-response attenuation characteristics for the A-, B-, and C-weighting networks.

SOUND PRESSURE WEIGHTING

Electronic circuits with sensitivity that varies with frequency similar to human hearing have been developed. There are three different internationally standardized characteristics called weighting networks A, B, and C. The A-network was designed to approximate the equal-loudness curves at low sound pressure levels, the B-network was designed for medium sound pressure levels, and the C-network was designed for high levels.

The weighting networks are the sound level meter's means of responding to some frequencies more than to others. The very low frequencies are discriminated against (attenuated) quite severely by the A-network, moderately attenuated by the B-network, and hardly attenuated at all by the C-network (Figure 9–7). Therefore, if the measured sound level of a noise is much higher on C-weighting than on A-weighting, much of the noise energy is probably of low frequency.

By definition, a weighted-frequency scale is simply a series of correction factors that are applied to sound pressure levels on an energy basis as a function of frequency. Shown in Table 9–C are the corrections for the A-weighting network at each of the octave-band center frequencies commonly used in noise measurements.

Table 9–C. *Octave-Band Correction Factors of the A-Weighted Network*

Octave-Band Center Frequency (Hz)	*A-Network Correction Factor (dB)*
31.5	–39.4
63	–26.2
125	–16.1
250	–8.6
500	–3.2
1,000	0
2,000	+1.2
4,000	+1.0
8,000	–1.1
16,000	–6.6

Adapted from ANSI, 1983.

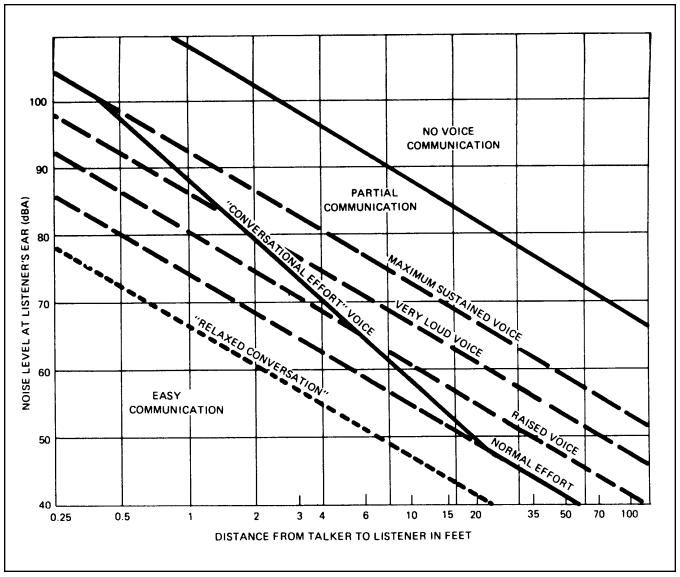


Figure 9–8. Distance at which ordinary speech can be understood (as a function of the A-weighted sound levels of the masking noise in an outdoor environment). (Reprinted from *Public Health and Welfare Criteria of Noise,* July 27, 1973, U.S. Environmental Protection Agency.)

The A-weighted sound level measurement has become popular in the assessment of overall noise hazard because it is thought to provide a rating of industrial broadband noises that indicates the injurious effects such noise has on human hearing.

As a result of its simplicity in rating the hazard to hearing, the A-weighted sound level has been adopted as the measurement for assessing noise exposure by the American Conference of Governmental Industrial Hygienists (ACGIH). The A-weighted sound level as the preferred unit of measurement was also adopted by the U.S. Department of Labor as part of its Occupational Safety and Health Standards. The A-weighted sound level has also been shown to provide reasonably good assessments of speech interference and community disturbance conditions and has been adopted by the U.S. Environmental Protection Agency (EPA) for these purposes (Figure 9–8).

OCCUPATIONAL DAMAGE-RISK CRITERIA

The purpose of damage-risk criteria is to define maximum permissible noise levels during given periods that, if not exceeded, would result in acceptable small changes in the hearing levels of exposed employees over a working lifetime. The acceptability of a particular noise level is a function of many variables.

Increasing attention is being given by regulatory agencies and industrial and labor groups to the effects of noise exposures on employees; therefore, equitable, reliable, and practical damage-risk noise criteria are needed.

A criterion is a standard, rule, or test by which a judgment can be formed. A criterion for establishing levels for damage-risk noise requires one or more standards for judgment. Damage-risk criteria can be developed once standards are selected by which the effects of occupational noise exposure on employees can be judged.

Hearing Ability

Tests for evaluating the ability to hear speech have been developed. These tests generally fall into two classes: those that measure the hearing threshold or the ability to hear very faint speech sounds and those that measure discrimination, or the ability to *understand* speech (see Chapter 4, The Ears).

Ideally, hearing impairment should be evaluated in terms of an individual's ability (or inability) to hear normal speech under everyday conditions. The ability of an individual to hear sentences and to repeat them correctly in a quiet environment is considered to be satisfactory evidence of adequate hearing ability. Hearing tests using pure tones are extensively employed to monitor the status of a person's hearing and the possible progression of a hearing loss. A person's ability to hear pure tones is related to the hearing of speech.

People who work in noisy environments should have their hearing checked periodically to determine whether the noise exposure is producing a detrimental effect on hearing. The noise-induced hearing losses that can be measured by pure-tone audiometry are the threshold shifts that constitute a departure from a specified baseline. This baseline, or normal hearing level, can be defined as the average hearing threshold of a group of young people who have no history of previous exposure to intense noise and no otological malfunction.

AMA *GUIDES*

Chapter 11.2 of the American Medical Association's (AMA) *Guides to the Evaluation of Permanent Impairment,* 5th edition (American Medical Association, copyright 2000) includes criteria for evaluating permanent impairment resulting from the principal dysfunctions of the ear. Permanent impairment is expressed in terms of impairment of the whole person.

Monaural hearing impairment is evaluated by determining hearing threshold levels for each ear at test frequencies of 500, 1,000, 2,000, and 3,000 Hz. If the average of these hearing levels is 25 dB or less, no impairment is considered to exist in the ability to hear everyday sounds under everyday listening conditions.

The AMA describes the method to convert monaural hearing impairments to a binaural hearing impairment. The binaural hearing impairment is then used to determine impairment of the whole person (see Chapter 4, The Ears).

Risk Factors

If the ear is subjected to high levels of noise for a sufficient period of time, some loss of hearing will occur. There are many factors that affect the degree and extent of hearing loss, including the following:

- ➢ The intensity of the noise (sound pressure level)
- ➢ The type of noise (frequency spectrum)
- ➢ The period of exposure each day (worker's schedule per day)
- ➢ The total work duration (years of employment)
- ➢ Individual susceptibility
- ➢ The age of the worker
- ➢ Coexisting hearing loss and ear disease
- ➢ The character of the surroundings in which the noise is produced
- ➢ The distance from the source
- ➢ The position of the ear with respect to sound waves

The first four factors are the most important, and they are called *noise exposure factors*. Thus, it is necessary to know not only the intensity of the noise, but also what type of noise it is and its duration.

Because of the complex relationship of noise and exposure time to threshold shift (reduction in hearing level) and its many possible contributory causes, the criteria designed to protect workers from hearing loss took many years to develop and establish.

The Intersociety Committee on Guidelines for Noise Exposure Control published the results of their study to

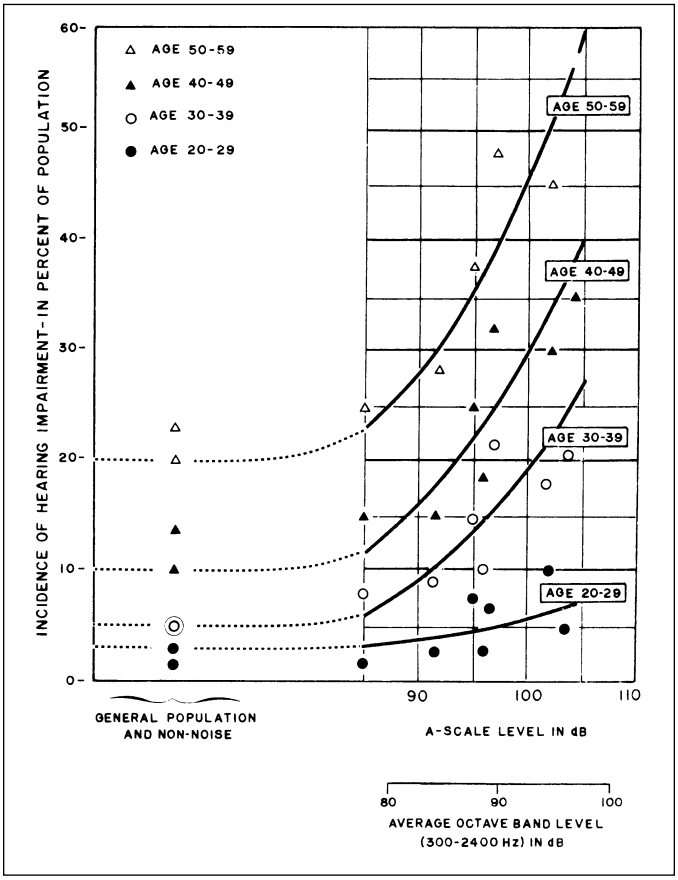


Figure 9–9. The incidence of hearing impairment in the general population and in selected populations by age group and by occupational noise exposure. (Reprinted with permission from the *American Industrial Hygiene Association Journal*.)

establish a basis for reliable noise criteria. A significant part of their report is shown graphically in Figure 9–9. The curves in the figure relate the incidence of significant hearing loss to age and the magnitude of noise exposure over a working lifetime.

Without attempting to explain the full significance of the graph, it can be stated that 20 percent of the general population between the ages of 50 and 59 experience hearing losses without having had any exposure to industrial noise, but groups of workers exposed to steady-state industrial noise over a working lifetime show a greater increase in the incidence of hearing loss.

For example, exposure to steady-state noise at 90 dB on the A-scale of the sound level meter (90 dBA) results in significant hearing losses in 27 percent of the exposed group. If the working lifetime exposure is 95 dBA, 36 percent of the group shows significant hearing loss.

Essentially, the graph in Figure 9–9 supplies industry and other interested groups with information from which the risk of developing compensable hearing loss among groups of workers exposed to noises of different magnitudes can be predicted.

Analysis of Noise Exposure

The critical factors in the analysis of noise exposure are the A-weighted sound level; the frequency composition, or spectrum, of the noise; and the duration and distribution of noise exposure during a typical workday.

It is currently believed that any exposure of the unprotected ear to sound levels above 115 dBA is hazardous and should be avoided. Exposure to sound levels below 70 dBA can be assumed to be safe and do not produce any permanent hearing loss. The majority of industrial noise exposures fall within this 45-dBA range; thus, additional information is required for evaluation of damage risk, such as the type of noise and duration of exposure.

It would be very helpful to know the predominant frequencies present and the contributions from each of the frequency bands that make up the overall level. It is currently believed that noise energy with predominant frequencies above 500 Hz has a greater potential for causing hearing loss than noise energy concentrated in the low-frequency regions. It is also believed that noises that have a sharp peak in a narrow-frequency band (such as a pure tone) present a greater hazard to hearing than noises of equal energy levels that have a continuous distribution of energy across a broad frequency range.

The incidence of noise-induced hearing loss is directly related to total exposure time. In addition, it is believed that intermittent exposures are far less damaging to the ear than are continuous exposures, even if the sound pressure levels for the intermittent exposures are considerably higher than those during continuous exposures. The rest periods between noise exposures allow the ear to recuperate.

At present, the deleterious effects of noise exposure and the energy content of the noise cannot be directly equated. For example, doubling the energy content does not produce twice the hearing loss. In general, however, the greater the total energy content of the noise, the shorter the time of exposure required to produce the same amount of hearing loss. However, the exact relation between time and energy is not known.

Another factor that should be considered in the analysis of noise exposures is the type of noise. For instance, impact noise is generated by drop hammers and punch presses, whereas steady-state noise is generated by turbines and fans. Impact noise is a sharp burst of sound; therefore, sophisticated instrumentation is necessary to determine the peak levels for this type of noise. Additional research must be done to fully define the effects of impact noise on the ear.

The total noise exposure during a person's normal working lifetime must be known to arrive at a valid judgment of how noise will affect that person's hearing. Instruments such as noise dosimeters can be used to determine the exposure pattern of a particular individual. Instruments such as sound level meters can be used to determine the noise exposure at a given instant in time (that is, during the time the test is being taken). An exposure pattern can be established using a series of such tests and the work history of the individual.

SOUND MEASURING INSTRUMENTS

A wide assortment of equipment is available for noise measurements, including sound survey meters, sound level meters, octave-band analyzers, narrowband analyzers, noise dosimeters, tape and graphic level recorders, impact sound level meters, and equipment for calibrating these instruments.

For most noise problems encountered in industry, the sound level meter and octave-band analyzer provide ample information (Figure 9–10).

Sound Level Meters

The basic instrument used to measure sound pressure variations in air is the sound level meter. This instrument contains a microphone, an amplifier with a calibrated attenuator, a set of frequency-response networks (weighting networks), and an indicating meter (Figure 9–11). The sound level meter is a sensitive electronic voltmeter that measures the electrical signal emitted from a microphone, which is ordinarily attached to the instrument. The alternating electrical signal emitted from the microphone is amplified sufficiently so that, after conversion to direct current by means of a rectifier, the signal can be displayed. An attenuator controls the overall amplification of the instrument. The response-versus-frequency characteristics of the amplified signal are controlled by the weighting networks.

Some sound level meters have a measurement range of about 40–140 dB (re: 20 μPa) without the aid of special accessory equipment. Special microphones permit measurement of lower or of considerably higher sound levels. An amplifier that can register the electrical output signal of the microphone is usually provided with the sound level meter so that it can be hooked up to other instruments for recording and analysis. The sound level meter is designed to be a device for field use and as such should be reliable, rugged, reasonably stable under battery operation, and lightweight.

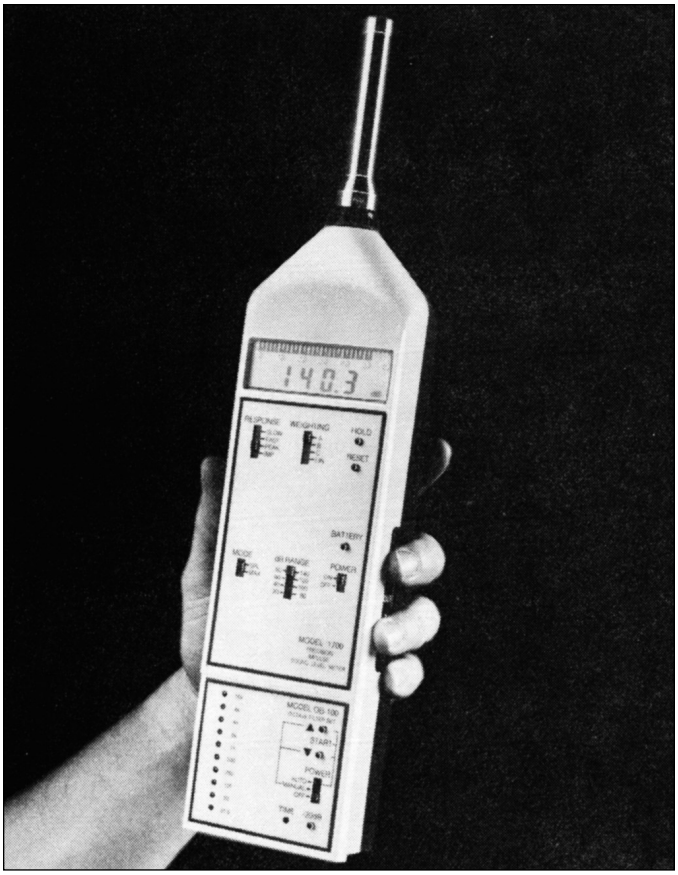


Figure 9–10. The multipurpose instrument shown here can be used as a sound level meter, octave-band analyzer, and impact/impulse noise meter. (Courtesy Quest Technologies.)

MICROPHONE

The microphone responds to sound pressure variations and produces an electrical signal that is processed by the sound level meter.

AMPLIFIER

The amplifier in a sound level meter must have a high available gain so that it can measure the low-voltage signal from a microphone in a quiet location. It should have a wide frequency range, usually on the order of 20–20,000 Hz. The range of greatest interest in most noise measurements is 50–6,000 Hz. The inherent electronic noise floor and hum level of the amplifier must be low.

ATTENUATORS

Sound level meters are used for measuring sounds that differ greatly in level. A small portion of this range is covered by the indicating meter. The rest of the range is covered by an adjustable attenuator, which is an electrical resistance network inserted into the amplifier to produce known ranges of signal level.

WEIGHTING NETWORKS

The sound level meter response at various frequencies can be controlled by electrical weighting networks. The response curves for these particular networks have been established in the American National Standards Institute's publication ANSI S1.4 1983– (R1997). C-weighting approximates a uniform response over the frequency range from 25–8,000 Hz. Changes in the electronic circuit are sometimes made to compensate for the response of particular microphones, so that the net response is uniform (flat) within the tolerance allowed by the standards. The C-weighting network is generally used when the sound level meter supplies a signal to an auxiliary instrument for a more detailed analysis. (The weighting networks are shown in Figure 9–7.) The A-weighting network is used to determine compliance with the OSHA standard.

METERING SYSTEM

After the electrical signal from the microphone is amplified and sent through the attenuators and weighting networks, the signal is used to drive a metering circuit. This metering circuit displays a value that is proportional to the electrical signal applied to it. The ANSI S1.4–1983 (R1997) standard for sound level meters specifies that the rms value of the signal should be indicated. This requirement corresponds to adding up the different components of the sound wave on an energy basis. When measuring sound, the rms value is a useful indication of the general energy content.

A running average of the rectified output of the metering circuit is displayed. The average time (or response speed) is determined by the meter ballistics and the response circuit chosen.

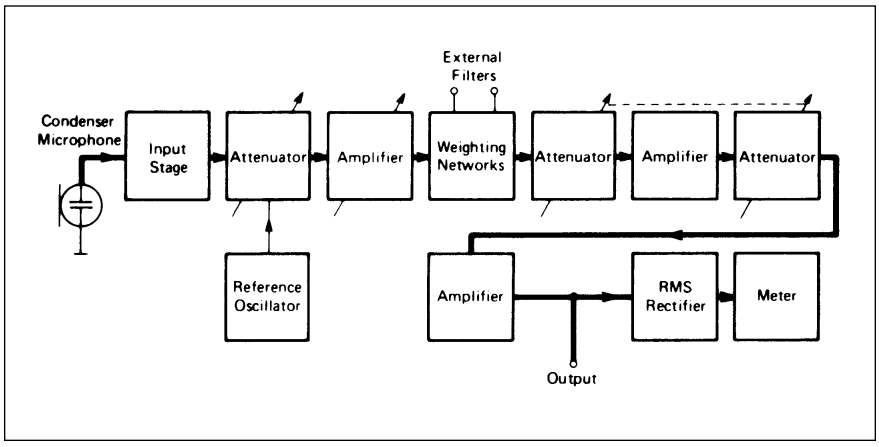


Figure 9–11. Schematic diagram of a sound level meter with auxiliary output.

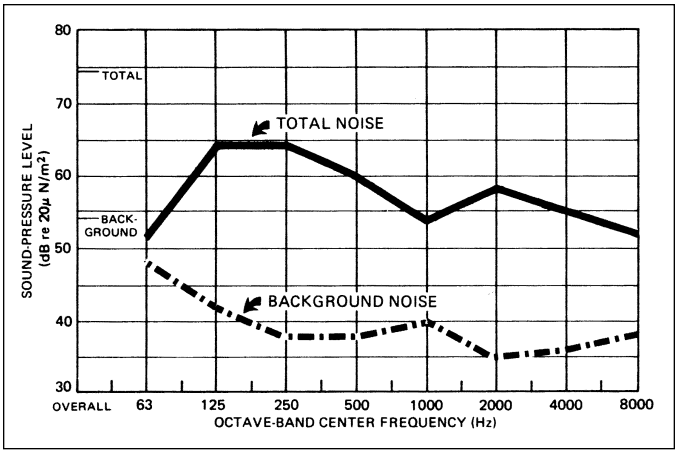


Figure 9–12. Data obtained from an octave-band analysis of a noise source, showing the total noise and the background noise levels when the noise source is not in operation.

Table 9–D. ***Octave-Band Mean Frequencies and Corresponding Band Limits ANSI S1.11–1986 (R1998)***

Lower Band Limit (Hz)	*Geometric Mean Frequency of Band (Hz)*	*Upper Band Limit (Hz)*
222	231.5	244
244	263.5	288
288	125.5	177
177	250	354
354	500	707
707	1,000	1,414
1,414	2,000	2,828
2,828	4,000	5,656
5,656	8,000	11,312

Two modes of operation—fast and slow—are provided on every sound level meter. In the fast mode, the meter responds relatively quickly to rapidly changing noise levels, whereas in the slow mode, the meter responds rather slowly. The use of each mode is best illustrated by example. If one were to measure the noise level of a passing vehicle, the fast mode would be used to obtain the maximum level. In a factory, where an average noise level is often more useful, the slow mode would be selected to reduce rapid, hard-to-read excursions. OSHA requires the use of slow response for measurements to check for compliance with its regulations.

Octave-Band Analyzers

For many industrial noise problems, it is necessary to use some type of analyzer to determine where the noise energy lies in the frequency spectrum. This is especially true if engineering control of noise problems is planned, because industrial noise is made up of various sound intensities at various frequencies (Figure 9–12).

In order to properly represent the total noise of a noise source, it is usually necessary to break the total noise down into its various frequency components—low frequency, high frequency, or middle frequency. This is necessary for two reasons: People react differently to low-frequency and high-frequency noises (for the same sound pressure level, high frequency noise is much more disturbing and is more capable of producing hearing loss than is low-frequency noise); and the engineering solutions for reducing or controlling noise are different for low-frequency and high-frequency noise (low-frequency noise is more difficult to control, in general).

It is conventional practice in acoustics to determine the frequency distribution of a noise by passing that noise through several different filters that separate the noise into 8 or 9 octaves on a frequency scale. Just as with an octave on a piano keyboard, an octave in sound analysis represents the frequency interval between a given frequency (such as 250 Hz) and twice that frequency (500 Hz).

A young, healthy ear is sensitive to sound frequency in the range from about 20 to 20,000 Hz. Most octave-band analyzing filters now cover the audio range from about 22 Hz to about 11,300 Hz in nine octave-frequency bands. These filters are identified by their geometric mean frequencies as shown in Table 9–D.

Notice that these filters are constant-percentage filters. The width of the band being utilized (bandwidth) is a fixed percentage of the frequency at which the instrument is operating. Octave-band filters have bandwidths that are 70.7 percent of the mean frequency (this is easily seen in the 1-kHz band).

For a more detailed analysis of the distribution of sound energy as a function of frequency, still narrower bands are used. The next commonly used division is a split of the octave into three parts.

Some of the mean frequencies for such a series would be, for example, 100, 125, 160, 200, 250, 315, 400, 500, 630, and 800 Hz. One-third–octave filters have bandwidths that are 23.2 percent of the mean frequency.

Still narrower band filters are available, such as one-tenth octave-band. The narrower the band for analysis, the more sharply defined the data.

The identification of pure tone components, when present, is an extremely useful diagnostic tool for locating and quieting the noise source.

Some noise sources have a well-defined frequency content. For example, the hum generated by a fan or blower is usually centered at the blade-passage frequency, which is the product of the number of blades of the fan multiplied by the speed (revolutions per second) of the fan.

The fundamental blade-passage frequency (f_B, in Hertz) of fans is given by the following equation:

$$f_B = \frac{(\text{rpm})\ (N)}{60} \tag{21}$$

where rpm = shaft rotational speed (revolutions per minute)
N = number of blades
60 = a constant to convert rpm to revolutions per second

Higher harmonics are usually present with diminished sound pressure amplitude at integral multiples of the fundamental (that is, $2f_B$, $3f_B$, . . .).

The above relation can also be used to predict the fundamental tones from blowers, gears, and so on by letting N represent the number of impeller lobes or gear teeth. For example, consider the following.

Example 4

What is the frequency of the predominant tone that would be emitted from an axial fan with four blades rotating at 6,000 rpm?

$$f_B = \frac{(\text{rpm})\ (N)}{60} = \frac{(6,000)\ (4)}{60} = 400 \text{ Hz} \qquad (22)$$

The fundamental blade-passage frequency is then 400 Hz. One would also expect additional tones at integral multiples of the predominant tone at

$f_2 = (2)(400) = 800$ Hz
$f_3 = (3)(400) = 1,200$ Hz
⋮
$f_N = (N)(400)$ Hz

The higher-frequency tones would have progressively diminished sound pressure amplitude.

Electrical transformers usually hum in frequencies that are multiples of 60 Hz. Positive-displacement pumps have a sound pressure distribution that is directly related to the pressure pulses on either the inlet or the outlet of the pump.

Noise resulting from the discharge of steam- or air-pressure relief valves has a frequency peak that is related to the pressure in the system and the diameter of the restriction preceding the discharge to the atmosphere. A peak energy content in any single octave band would provide information as to the predominant frequency of a particular noise source.

Sound level meters have evolved from relatively simple devices capable of measuring weighted sound levels and performing octave-band frequency analysis to highly sophisticated instruments that serve as the front end of a data acquisition system.

The instrument shown in Figure 9–13, for example, not only functions as a sound level meter and octave- or one- third octave-band analyzer but is also capable of measuring all the relevant parameters defined by OSHA and ANSI standards for industrial and environmental noise. The output of this instrument can be recorded, printed, or transferred to a personal computer for additional analysis or graphical presentation.

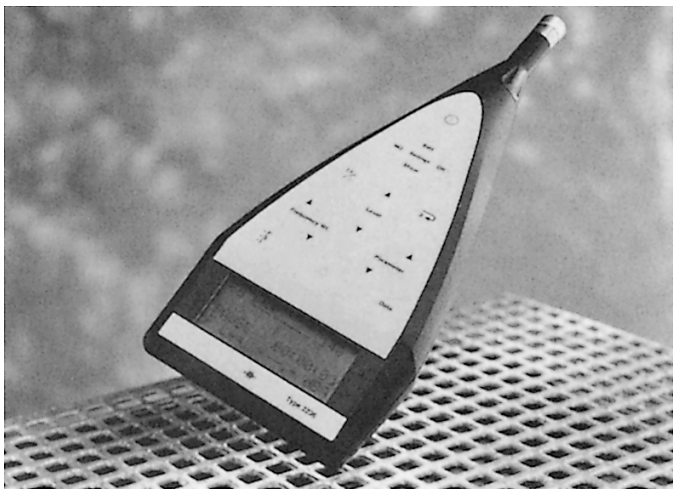


Figure 9–13. Precision integrating sound level meter. (Courtesy Bruel & Kjaer Instruments, Inc.)

Figure 9–14. Dosimeter being worn to monitor noise exposure. (Courtesy Quest Technologies.)

Noise Dosimeters

In many work environments, it may not be adequate to measure noise exposure at a fixed location for the duration of a workshift. Some workers move about to several locations in the course of their duties or perform a variety of operations during the day and are therefore subjected to different noise levels. The practical way to measure the noise exposure in these circumstances is with a noise-exposure monitor, or dosimeter, that can be worn by the worker and that moves with the worker during the day. The noise dosimeter records the noise energy to which the worker is exposed during the workshift.

A dosimeter (Figure 9–14) includes a microphone placed in the person's hearing zone and the remainder of the instru-

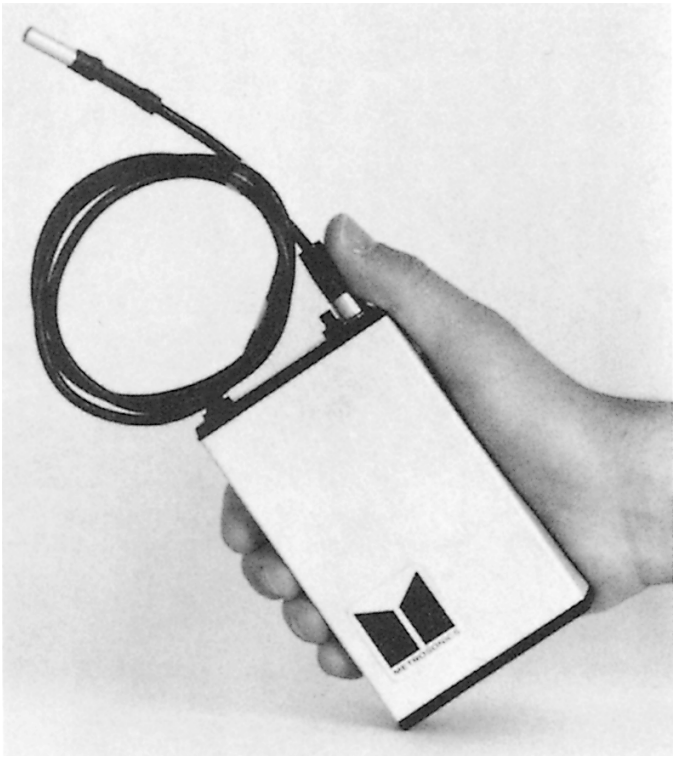


Figure 9–15. Noise dosimeter/multipurpose integrating sound level meter. (Courtesy Metrosonics, Inc.)

ment, which automatically computes the desired noise measures—most commonly the daily noise dose. This measure is used to check for compliance with the OSHA noise standard.

Dosimeters have evolved from simple devices that compute single-number exposure measures to highly sophisticated monitors that compute and store comprehensive data on the sound field encountered by the subject. The instrument shown in Figure 9–15, for example, not only functions as a noise dosimeter, but also as a multipurpose integrating sound level meter. It is also capable of producing several types of printed reports, including statistical analyses of data and graphical time history reports.

It is important to recognize the fact that dosimeters were derived directly from sound level meters. Dosimeters were developed to simplify measurement and computational procedures. In order to obtain comparable results, dosimeters must correctly duplicate the dynamic characteristics of sound level meters. Specific requirements prescribing these characteristics are set forth in the American National Standards Institute (ANSI) Standard S1.25–1991 (R1997), *Specification for Personal Noise Dosimeters.*

SOUND SURVEYS

Sound measurement falls into two broad categories: source measurement and ambient-noise measurement. Source measurements involve the collection of acoustic data for the purpose of determining the characteristics of noise radiated by a source. The source might be a single piece of equipment or a combination of equipment or systems. For example, a single electrical motor or an entire facility can be considered a noise source.

Ambient-noise measurements can be used to study a single sound level or to make a detailed analysis showing hundreds of components of a complex vibration. The number of measurements taken and the type of instruments needed depend on the information that is required. If compliance with a certain noise specification must be checked, the particular measurement required is reasonably clear. Only some guidance as to the selection of instruments and their use is needed. But if the goal is to reduce the noise produced by industrial operations in general, the situation is more complex, and careful attention to the acoustic environment is essential.

Measurement of the noise field may require using different types of sound level–measuring instruments. These measurements must be repeated as changes in noise-producing equipment or operating procedures occur.

The use of the dBA scale for preliminary noise measurement greatly simplifies the collection of sound level survey data. Detailed sound level survey and octave-band analysis data are necessary to provide sufficient information so that the proper remedial measures for noise-control procedures can be determined. Calibration checks of the instruments should be made before, during, and after the sound level survey.

Source Measurements

Source measurements frequently are made in the presence of noise created by other sources that form the background- or ambient-noise level. Although it is not always possible to make a clear distinction between source- and ambient-noise measurement, it is important to understand that source measurements describe the characteristics of a particular sound source, while ambient-noise measurements describe the characteristics of a sound field of largely unspecified or unknown sources.

A uniform, standard reporting procedure should be established to ensure that sufficient data are collected in a form suitable for subsequent analysis. To be effective, this standard reporting procedure should include detailed descriptions of the techniques of measurement position, operating conditions, instrument calibration, exposure time, amplitude patterns, and other important variables.

Several forms have been devised to record data obtained during a screening survey. Use of these forms facilitates the recording of pertinent information that will be extremely useful if more detailed studies are conducted later. An employee noise-exposure survey is conducted by measuring noise levels at each workstation that an employee occupies throughout the day or by acquiring a sufficient sampling of data at each workstation so that the exposure of an employee while at that workstation can be evaluated. Workstations that pose particular noise-exposure hazards can be readily identified by using measured sound level contours if these are obtained in adequate detail.

In many industrial situations, however, it is extremely difficult to accurately evaluate the noise exposure to which a

particular worker is subjected. This is due in part to the fact that the noise level to which the stationary worker is exposed throughout the workday fluctuates, making it difficult to evaluate compliance or noncompliance with the OSHA regulations. Another problem arises when a worker's job requires that he or she spend time in areas where the noise levels vary from very low to very high.

Because of the fluctuating nature of many industrial noise levels, it would not be accurate or meaningful to use a single sound level meter reading to estimate the daily time-weighted average (TWA) noise level.

Preliminary Noise Survey

A hearing conservation program should start with a preliminary facilitywide noise level survey using appropriate sound level–measuring equipment to locate operations or areas where workers may be exposed to hazardous noise levels.

Those conducting the survey have to decide whether to purchase sound level–measuring equipment and train personnel to use it or to contract the work to an outside firm. The extent of the noise problem, the size of the facility, and the nature of the work affect this decision. In most facilities, noise surveys are conducted by a qualified engineer, an audiologist, an industrial hygienist, or a safety and health professional.

A noise survey should be carried out at work areas where it is difficult to communicate in normal tones. A common rule of thumb is that if you have to shout to communicate at a distance of three feet, noise levels may be excessive. A noise survey should also be performed if, after being exposed to high noise levels during their workshift, workers notice that speech and other sounds are muffled for several hours or they develop ringing in the ears.

As a general guideline for conducting a noise survey, the information recorded should be sufficient to allow another individual to take the report, use the same equipment, find the various measurement locations, and, finally, reproduce the measured and/or recorded data.

The preliminary noise survey normally does not define the noise environment in depth and therefore should not be used to determine employee exposure time and other details. The preliminary noise survey simply supplies sufficient data to determine whether a potential noise problem exists and, if so, to indicate how serious it is.

Detailed Noise Survey

From the preliminary noise survey, it is relatively easy to determine specific locations that require more detailed study and attention. A detailed noise study should then be made at each of these locations to determine employees' TWA exposures.

The purposes of a detailed noise survey are the following:

- ➢ To obtain specific information on the noise levels existing at each employee's work station
- ➢ To develop guidelines for establishing engineering and/or administrative controls
- ➢ To define areas where hearing protection will be required
- ➢ To identify those work areas where audiometric testing of employees is desirable and/or required

In addition, detailed noise survey data can be used to develop engineering control policies and procedures and to determine whether specific company, state, or federal requirements have been complied with.

An effective hearing conservation program always starts with the question, "Does a noise problem exist?" The answer must not be based simply on the subjective feeling that the problem exists but on the results of a careful technical definition of the problem. Answers to the following questions must be obtained:

- ➢ How noisy is each work area?
- ➢ What equipment or process is generating the noise?
- ➢ Which employees are exposed to the noise?
- ➢ How long are they exposed?

Line supervisors can provide basic job function information concerning the duration of operation, the types of noise-producing equipment in work areas, and the percentage of time a worker spends in each of the areas. Production records can be examined, and on-site evaluation can provide information as to the extent of the noise problems.

The noise survey should be made using a general-purpose sound level meter that meets standards set by ANSI S1.4 1983 (R1997). The sound level meter should be set for A-scale slow response.

Measurements of noise exposure should be taken at approximate ear level (Figure 9–16). No worker should be exposed to steady-state or interrupted steady-state sound levels that exceed the maximum listed in the current noise stan-

Figure 9–16. Take sound level measurements near an employee's workstation.

dard. Other information should include the name of the individual making the noise survey as well as the date, location of measurement, and time the measurement was made. The serial numbers of the sound level meters and the date of calibration are also essential for compliance records.

The noise survey procedure is a three-step process.

STEP 1: AREA MEASUREMENTS

Using a sound level meter set for A-scale slow response, the regularly occurring maximum noise level and the regularly occurring minimum noise level are recorded at the center of each work area. (For measurement purposes, the size of the work area should be limited to 1,000 sq ft [93 sq m] or smaller.) If the maximum sound level in a work area does not exceed 80 dBA, it can be assumed that all employees in that area are working in an environment with an acceptable noise level. If the noise levels measured at the center of the work area fall between 80 and 92 dBA, then more information is needed.

Sound level contours (Figure 9–17) can be used during this screening survey to identify workstations that may pose particular noise-exposure hazards. Sound level contours provide a visual depiction of the degree of the noise hazard in a work area, at a particular time.

To construct a sound level contour, the work area is divided into a grid whose lines are evenly spaced at an approximate distance of 10 ft (3.05 m). A-weighted sound level measurements are recorded at each measurement position. When the observed sound levels vary significantly, then the grid spacing should be decreased. It is usually necessary to decrease the grid spacing in the proximity of dominant noise sources due to rapidly changing sound levels. The contour lines drawn in Figure 9–17 are based on 2-dBA changes in the measured sound level.

STEP 2: WORKSTATION MEASUREMENTS

To evaluate the noise exposure for people working in locations where measurements at the center of the work area range from 80–92 dBA, measurements should be made at each employee's normal workstation. If the level varies on a regular basis, both the maximum and minimum levels should be recorded. If the noise level never goes below 90 dBA, an unsatisfactory noise exposure is indicated. If the measured level is never greater than 85 dBA, the noise exposure to which the employee is subjected can be regarded as satisfactory.

STEP 3: EXPOSURE DURATION

At workstations where the regularly occurring noise varies above and below the 85-dBA level, further analysis is needed.

If an employee has varying work patterns in different work areas, it is necessary to ascertain the sound level and duration of noise exposure within each work area. A breakdown of hours worked in each area can be obtained by consulting the employee or the employee's supervisor, or by visual monitoring. A briefing/debriefing approach for a particular day's activities can also be used. This approach consists of requesting each employee to keep a general work area/time log of his or her daily activities. The employee is then debriefed at the end of the work period to ensure that sufficient information was logged. In many cases, it may be desirable for an employee to wear a noise dosimeter that records daily exposure in terms of the current OSHA requirements.

The procedure for determining an employee's daily noise-exposure rating is discussed in the section that follows.

General Classes of Noise Exposure

There are three general classes into which occupational noise exposures can be grouped: continuous noise, intermittent noise, and impact-type noise.

CONTINUOUS NOISE

Continuous noise is normally defined as broadband noise of approximately constant level and spectrum to which an employee is exposed for a period of 8 hours per day, 40 hours per week. A large number of industrial operations fit into this class of noise exposure. Most damage-risk criteria are written for this type of noise exposure because it is the easiest to define in terms of amplitude, frequency content, and duration.

The OSHA Noise Standard, 29 *CFR* 1910.95(a) and (b), establishes permissible employee noise exposures in terms of duration in hours per day at various sound levels. The standard requires that the employer reduce employee exposures

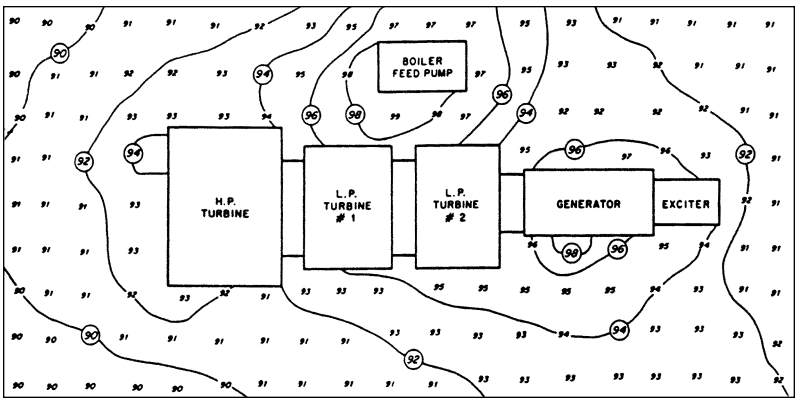


Figure 9–17. Sound level contours: operating-level turbine building. (From Di Blasi et al., 1983.)

to the allowable level by use of feasible engineering or administrative controls. The standard defines the permissible exposure level (PEL) as that noise dose that would result from a continuous 8-hour exposure to a sound level of 90 dBA. This is a dose of 100 percent. Doses for other exposures that are either continuous or fluctuating in level are computed relative to the PEL based on a 5-dBA trading relationship between noise level and exposure time (Table 9–E).

Every 5-dBA increase in noise level cuts the allowable exposure time in half. This is known as a 5-dB exchange rate.

When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the fractions $C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n$ exceeds 100 percent, the mixed exposure should be considered to exceed the limit value. C_n indicates the total time of exposure at a specified noise level, and T_n indicates the total time of exposure permitted at that level.

When employees are exposed to different noise levels during the day, the mixed exposure, E_m, must be calculated by using the following formula:

$$E_m = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \cdots + \frac{C_n}{T_n} \qquad (23)$$

where C_n = the amount of time an employee was exposed to noise at a specific level
T_n = the amount of time the employee can be permitted to be exposed to that level

If the sum of the fractions equals or exceeds 1, the mixed exposure is considered to exceed the allowable limit value, according to the OSHA standard. Daily noise dose (D) is an expression of E_m in percentage terms. For example, $E_m = 1$ is equivalent to a noise dose of 100 percent. (Note: OSHA does not consider noise levels below 90 dBA in determining the need for engineering controls.)

Example 5
An employee is exposed to the following noise levels during the workday:
- 85 dBA for 3.75 h
- 90 dBA for 2 h
- 95 dBA for 2 h
- 110 dBA for 0.25 h

Thus, the daily noise dose is as follows:

$$D = 100\left(\frac{3.75}{\text{no limit}} \quad \text{or} \quad 0 + \frac{2}{8} + \frac{2}{4} + \frac{0.25}{0.50}\right) = 125\% \qquad (24)$$

Because the dose exceeds 100 percent, the employee received an excessive exposure during the workday.

The permissible exposures given in Table 9–E are based on the presence of continuous noise rather than intermittent or impact-type noise. By OSHA definition, "if the variations in noise level involve maxima at intervals of one second or less, it is considered to be continuous."

Table 9–E. ***OSHA Permissible Noise Exposures***

Duration Per Day (hours)	*Sound Level, Slow Response (dBA)*
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Note: When the daily noise exposure is composed of two or more periods of noise exposure of different leveis, their combined effect should be considered, rather than the individuai effect of each. If the sum of the fractions $C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n$ exceeds 100 percent, the mixed exposure should be considered to exceed the iimit value. C_n indicates the total time of exposure at a specified noise level, and T_n indicates the total time of exposure permitted at that level.

Example 6
A drill runs for 15 seconds and is off 0.5 second between operations. This noise is rated at its "on" level for an entire eight-hour day. The noise generated by the drill would be "safe" only if the level were 90 dBA or less.

Further interpretation of the OSHA standard indicates that exposure above 115 dBA is not permissible for any length of time.

As discussed earlier, daily noise dose can be measured using a noise dosimeter. For OSHA use, the dosimeter must have a 5-dB exchange rate, 90-dBA criterion level, slow response, and either an 80-dBA or 90-dBA threshold gate for the appropriate standard to be evaluated. OSHA prescribes a 90-dBA threshold level for compliance with 29 *CFR* 1910.95 (a) and (b), which require implementation of engineering or administrative controls. An 80-dBA threshold is prescribed in 29 *CFR* 1910.95 (d) for monitoring situations for hearing conservation.

INTERMITTENT NOISE

Exposure to intermittent noise can be defined as exposure to a given broadband sound-pressure level several times during a normal working day. The inspector or facility supervisor who periodically makes trips from a relatively quiet office into noisy production areas may be subject to this type of noise.

With steady noises, it is sufficient to record the A-weighted sound level attained by the noise. With noises that are not steady, such as impulsive noises, impact noises, and the like, the temporal character of the noise requires additional specification. Both the short-term and long-term variations of the noise must be described. Nonsteady

noise-exposure measurements are most easily made using dosimeters.

IMPACT-TYPE NOISE

Impact-type noise is a sharp burst of sound, and sophisticated instrumentation is necessary to determine the peak levels for this type of noise. Noise types other than steady ones are commonly encountered. In general, sounds repeated more than once per second can be considered as steady. Impulsive or impact noise, such as that made by hammer blows or explosions, is generally less than one-half second in duration and does not repeat more often than once per second. Employees should not be exposed to impulsive or impact noise that exceeds a peak sound pressure level of 140 dB.

NOISE-CONTROL PROGRAMS

The degree of noise reduction required is determined by comparing the measured levels with acceptable noise levels. The next step is to consider various noise-control measures such as making alterations in engineering design, limiting the time of exposure, or using personal protective devices to achieve the desired level of reduction.

Every noise problem can be broken down into three parts: a source that radiates sound energy, a path along which the sound energy travels, and a receiver such as the human ear (Figure 9–18). The "system" approach to noise-problem analysis and control assists in understanding both the problem and the changes that are necessary for noise reduction. If each part of the system—source, path, and receiver—is examined in detail, the overall problem is greatly simplified. To help translate these principles into practical terms, specific examples of controlling industrial noise exposure are outlined in this section.

Source

The most desirable method of controlling a noise problem is to minimize the noise at the source. This generally means

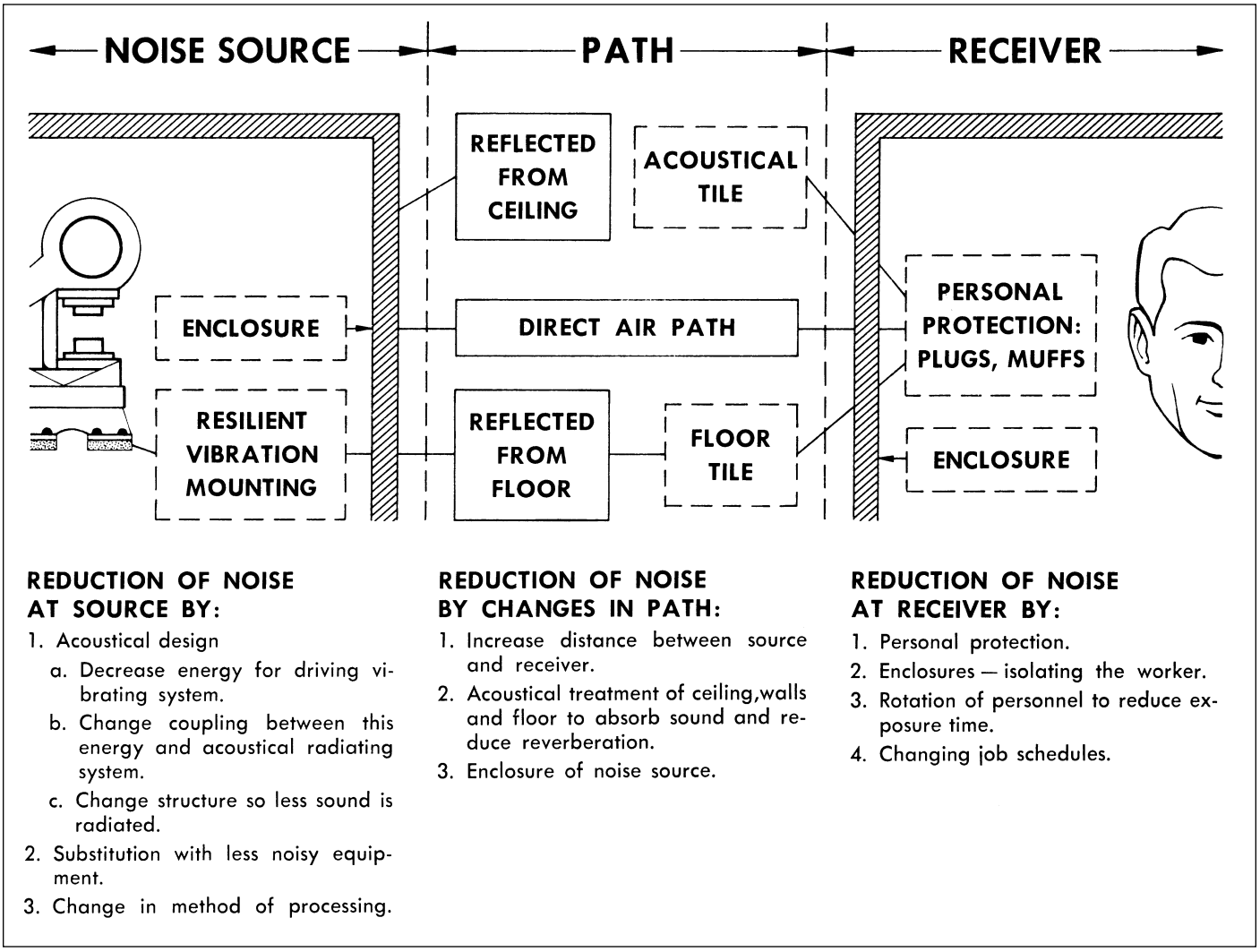


Figure 9–18. Every noise problem can be broken down into three component parts: a source that radiates sound energy, a path along which the sound energy travels, and a receiver such as the human ear.

modifying existing equipment and structures or possibly introducing noise-reduction measures at the design stage of new machinery and equipment.

Noise Path

Because the desired amount of noise reduction cannot always be achieved by control at the source, modification along the noise path and at the receiver must also be considered.

Noise reduction along the path can be accomplished in many ways: by shielding or enclosing the source, by increasing the distance between the source and the receiver, or by placing a shield between the source and the receiver. Noise can be reduced along the path by means of baffles and enclosures placed over noise-producing equipment to minimize the transmission of noise to areas occupied by employees. Use of acoustical material on walls, ceilings, and floors to absorb sound waves and to reduce reverberations can result in significant noise reduction.

Noise produced by a source travels outward in all directions. If all of the walls, the floor, and the ceiling are hard, reflecting surfaces, all the sound is reflected again and again. The sound level measured at any point in the room is the sum of the sound radiated directly by the source plus all the reflected sounds. Practically all industrial machine installations are located in such environments. These locations are known as semireverberant. Noise measured around a machine in a semireverberant location is the sum of two components: the noise radiated directly by the machine and the noise reflected from the walls, floor, and ceiling.

Close to the machine, most of the noise is radiated directly by the machine. Close to the walls, the reflected component may be predominant. Sound-absorption materials applied to the walls and ceiling can reduce the reflected noise but has no effect on the noise directly radiated by the source.

Enclosures

In many cases, the purpose of an acoustic enclosure is to prevent noise from getting inside. Soundproof booths for machine operators and audiometric testing booths for testing the hearing of employees are examples of such enclosures. More often, however, an enclosure is placed around a noise source to prevent noise from getting outside. Enclosures are normally lined with sound-absorption material to decrease internal sound pressure buildup.

Noise can best be prevented from entering or leaving an enclosure by sealing all outlets. In extreme cases, double structures can be used. Special treatment, including the use of steel and lead panels, is available to prevent noise leakage in certain cases. Gaskets around doors can also reduce noise transmission from one space to another.

Control Measures

Noise control can often be designed into equipment so that little or no compromise in the design goals is required. Noise control measures undertaken on existing equipment are usually more difficult. Engineering control of industrial noise problems requires the skill of individuals who are highly proficient in this field.

Noise-control strategies require careful objective analysis on both a practical and economic basis. Complete redesign requires that product and equipment designers consider noise level a primary product or equipment specification in the design of all new products. Full replacement of all products or equipment would eventually take place, the schedule depending on the service life of each. Many designers feel this approach minimizes the cost increases associated with noise-control measures. Existing products or equipment modifications would require manufacturers to modify or replace existing products and equipment to lower the noise levels of noisy equipment.

The existing equipment within any facility was probably selected because it was economical and efficient. However, careful acoustic design can result in quieter equipment that would even be more economical to operate than noisier equipment. Examples of noise-control measures applied at the source include the substitution of quieter machines, the use of vibration-isolation mountings, and the maximum possible reduction of the external surface areas of vibrating parts. Machines mounted directly on floors and walls can cause them to vibrate, resulting in sound radiation. Proper machine mounting can isolate the machines and reduce the transmission of vibrations to the floors and walls.

Although substitution of less noisy machines may have limited application, there are certain areas in which substitution has a potentially wider application. Examples include using "squeeze"-type equipment instead of drop hammers, welding instead of riveting, and instituting chemical cleaning of metal rather than high-speed polishing and grinding.

ENGINEERING

When starting a noise-reduction program, it is most desirable to apply engineering principles that are designed to reduce noise levels. The application of known noise-control principles can usually reduce any noise to any desired degree. However, economical considerations or operational necessities can make some applications impractical.

Engineering controls are procedures other than administrative or personal protection procedures that reduce the sound level either at the source or within the hearing zone of workers. The following are examples of engineering principles that can be applied to reduce noise levels.

1. Maintenance:
   a. replacement or adjustment of worn, loose, or unbalanced parts of machines
   b. lubrication of machine parts and use of cutting oils
   c. use of properly shaped and sharpened cutting tools
2. Substitution of machines:
   a. larger, slower machines for smaller, faster ones
   b. step dies for single-operation dies

   c. presses for hammers
   d. rotating shears for square shears
   e. hydraulic presses for mechanical presses
   f. belt drives for gears
3. Substitution of processes:
   a. compression riveting for impact riveting
   b. welding for riveting
   c. hot working for cold working
   d. pressing for rolling or forging
4. Reduction of the driving force of vibrating surfaces:
   a. reduction of the forces
   b. minimization of rotational speed
   c. isolation
5. Reduction of the response of vibrating surfaces:
   a. damping
   b. additional support
   c. increased stiffness of the material
   d. increased mass of vibrating members
   e. change in the size to change resonance frequency
6. Reduction of the sound radiation from vibrating surfaces:
   a. reduction of the radiating area
   b. reduction of the overall size
   c. perforation of the surfaces
7. Reduction of the sound transmission through solids:
   a. use of flexible mountings
   b. use of flexible sections in pipe runs
   c. use of flexible-shaft couplings
   d. use of fabric sections in ducts
   e. use of resilient flooring
8. Reduction of the sound produced by gas flow:
   a. use of intake and exhaust mufflers
   b. use of fan blades designed to reduce turbulence
   c. use of large, low-speed fans instead of smaller, high-speed fans
   d. reduction of the velocity of fluid flow (air)
   e. increase in the cross section of streams
   f. reduction of the pressure
   g. reduction of air turbulence
9. Reduction of noise by reducing its transmission through air:
   a. use of sound-absorptive material on walls and ceiling in work areas
   b. use of sound barriers and sound absorption along the transmission path
   c. complete enclosure of individual machines
   d. use of baffles
   e. confinement of high-noise machines to insulated rooms
10. Isolation of the operator by means of a relatively soundproof booth

Some of the noise-control measures described here can be executed quite inexpensively by facility personnel. Other controls require considerable expense and highly specialized technical knowledge to obtain the required results. The services of competent acoustical engineers should be contracted when planning and carrying out engineering noise-control programs.

The possibility that excessive facility noise levels exist should be considered at the planning stage. Vendors supplying machinery and equipment should be advised that specified low noise levels will be considered in the selection process. Suppliers should be asked to provide information on the noise levels of currently available equipment. The inclusion of noise specifications in purchase orders has been used successfully to obtain quiet equipment. If purchasers of industrial equipment demand quieter machines, designers will give more consideration to the problem of noise control.

It is not enough to specify that the sound pressure level of a single machine shall be 90 dBA or less at the operator's station; if another identical machine is placed nearby, the sound level produced by the two machines could be 93 dBA at the operator's station. (As mentioned earlier in this chapter, an increase of 3 dB represents a doubling of sound energy.)

To estimate the effect of a given machine on the total work environment, it is necessary to know the sound power that the machine produces. If there is no operator's work station in the machine's immediate vicinity, the sound power specifications may be sufficient; if, however, there is an operator in the near-sound field, more information is generally needed.

Objectionable noise levels that are by-products of manufacturing operations are found in almost every industry. Practical noise-control measures are not easy to develop, and few ready-made solutions are available. Unfortunately, a standard technique or procedure that can be applied to all or even most situations cannot be presented here. The same machine, process, or noise source in two different locations can present two entirely different problems that must be solved in two entirely different ways.

Noise-control techniques are now being incorporated into products during the design stage. Machine tool buyers are one group who currently specify maximum noise levels in their purchase orders. Equipment can be designed with lower noise levels, but performance tradeoffs involving weight, size, power consumption, and perhaps increased maintenance costs may be necessary. These new, quieter products will probably weigh more, be bigger and bulkier, cost more, and be more difficult and expensive to service and maintain.

To attain quieter products, the engineer must be prepared to trade off, to some degree, many of the design goals that have been achieved in response to market demands. However, lightweight, low-cost, portable machines that are easily operated and simply maintained should not be cast aside lightly, even though price increases may be inevitable. The cost/benefit relationship should be examined in each case. In addition to paying higher prices for original equipment, the user (both as a consumer and as a taxpayer) pays for increased indirect costs.

The success of a noise-reduction project usually depends on the ingenuity with which basic noise-control measures can be applied without decreasing the maximum use and accessibility of the machine or other noise source that is being quieted.

ADMINISTRATIVE CONTROLS

There are many operations in which the exposure of employees to noise can be controlled administratively; for instance, production schedules can simply be changed or jobs rotated so that individual workers' exposure times are reduced. Employees can be transferred from job locations with high noise levels to job locations with lower ones if this procedure would make their daily noise exposure acceptable.

Administrative controls also include scheduling machine operating times so as to reduce the number of workers exposed to noise. For example, if an operation is performed during only one eight-hour day per week, and the operator is overexposed on that one day, it might be possible to perform the operation in two half-days of four hours each. The employee might then not be overexposed.

Employees who are particularly susceptible to noise can be transferred and allowed to work in a less noisy area. The benefits from transferring employees can be limited, however, because personnel problems can be caused due to loss of seniority and prestige and lower productivity and pay.

Administrative controls include any administrative decision that results in lower noise exposure, such as complying with purchase agreements that specify maximum noise levels at the operator's position.

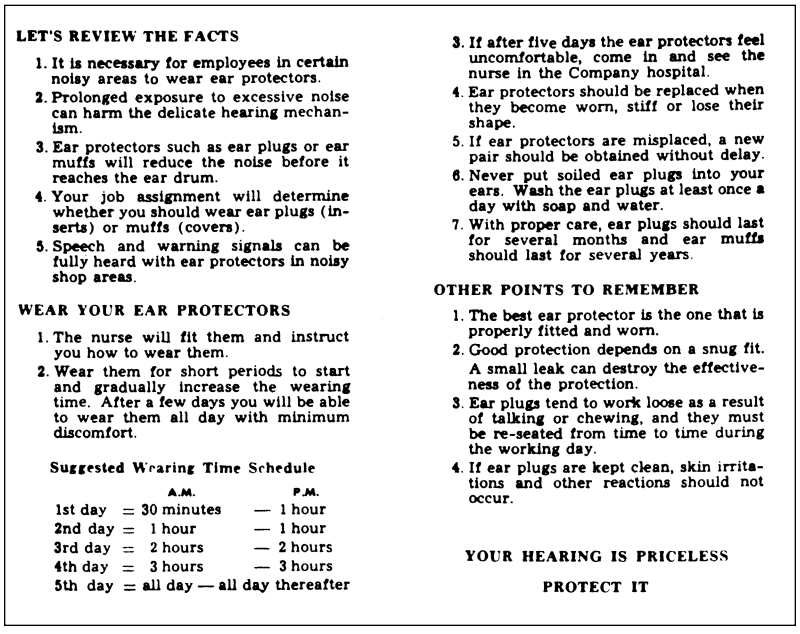
The sound level specification that is made part of a purchasing agreement must be more than just a general compliance statement such as "Must meet the requirements of the OSHA." It is important to realize that OSHA sets allowable noise limits relative to the exposure of the people involved. OSHA does not set specific standards for noise-generating equipment. The OSHA noise standard is not intended to be used as an equipment design specification and thus cannot be used as such.

PERSONAL HEARING PROTECTION

Pending the application of engineering control measures, employee exposure to noise can be reduced by the mandatory use of hearing- protective devices. Occupational noise regulations require that whenever employees are exposed to excessive noise levels, feasible administrative or engineering controls should be used to reduce those levels. When these control measures cannot be completely accomplished, or while such controls are being initiated, personnel should be protected from the effects of excessive noise levels. Such protection can, in most cases, be provided by wearing suitable hearing-protection devices. Once management has decided that hearing protectors should be worn, the success of such a program depends largely on the method of initiation used and on the proper indoctrination of supervisory personnel and workers. Supervisors should set an example by wearing their hearing protectors when they go into noisy areas.

Some companies have found it very helpful to meet with employees or their representatives to thoroughly review the contemplated protection program and reach an understanding of the various problems involved. This process includes reviewing work areas where hearing protection will be provided or required and complying with state and federal regulations that require the use of hearing-protective devices.

Hearing-protective devices. Hearing-protective devices such as earplugs and earmuffs have one serious drawback—they do nothing to reduce or eliminate the hazard. Their failure means immediate exposure to the hazard. The fact



LET'S REVIEW THE FACTS

1. It is necessary for employees in certain noisy areas to wear ear protectors.
2. Prolonged exposure to excessive noise can harm the delicate hearing mechanism.
3. Ear protectors such as ear plugs or ear muffs will reduce the noise before it reaches the ear drum.
4. Your job assignment will determine whether you should wear ear plugs (inserts) or muffs (covers).
5. Speech and warning signals can be fully heard with ear protectors in noisy shop areas.

WEAR YOUR EAR PROTECTORS

1. The nurse will fit them and instruct you how to wear them.
2. Wear them for short periods to start and gradually increase the wearing time. After a few days you will be able to wear them all day with minimum discomfort.

Suggested Wearing Time Schedule

	A.M.	P.M.
1st day	= 30 minutes	— 1 hour
2nd day	= 1 hour	— 1 hour
3rd day	= 2 hours	— 2 hours
4th day	= 3 hours	— 3 hours
5th day	= all day	— all day thereafter

3. If after five days the ear protectors feel uncomfortable, come in and see the nurse in the Company hospital.
4. Ear protectors should be replaced when they become worn, stiff or lose their shape.
5. If ear protectors are misplaced, a new pair should be obtained without delay.
6. Never put soiled ear plugs into your ears. Wash the ear plugs at least once a day with soap and water.
7. With proper care, ear plugs should last for several months and ear muffs should last for several years.

OTHER POINTS TO REMEMBER

1. The best ear protector is the one that is properly fitted and worn.
2. Good protection depends on a snug fit. A small leak can destroy the effectiveness of the protection.
3. Ear plugs tend to work loose as a result of talking or chewing, and they must be re-seated from time to time during the working day.
4. If ear plugs are kept clean, skin irritations and other reactions should not occur.

YOUR HEARING IS PRICELESS

PROTECT IT

Figure 9–19. An example of a flyer distributed to all company employees who are required to wear some form of hearing protection. The flyer highlights care and use of the protectors.

that a hearing protector can become ineffective without the knowledge of the wearer is particularly serious. Training on the purpose, benefits, proper fitting, use, and care of hearing protectors is essential to the success of the program and is required by OSHA. Distributing a flyer (Figure 9–19) highlighting the care and use of the hearing protector is also helpful.

Personal hearing-protective devices are acoustic barriers that reduce the amount of sound energy transmitted through the ear canal to receptors in the inner ear.

The sound attenuation (reduction) capability of a hearing-protective device (in decibels) is the difference in the measured hearing threshold of an observer wearing hearing protectors (test threshold) and the measured hearing threshold when the observer's ears are unprotected (reference threshold).

Inserts or muffs are hearing-protective devices that are in common use today. The insert-type protector attenuates noise by plugging the external ear canal, whereas the muff-type protector encloses the auricle of the ear to provide an acoustic seal. The effectiveness of hearing-protective devices depends on several factors that are related to the manner in which the sound energy is transmitted through or around the device. Figure 9–20 shows four pathways by which sound can reach the inner ear when hearing-protective devices are worn: seal leaks, material leaks, hearing-protective device vibration, and conduction through bone and tissue.

Seal leaks. For maximum protection, the device must form a virtually airtight seal against the ear canal or the side of the head. Inserts must accurately fit the contours of the ear canal, and muffs must accurately fit the area surrounding the external ear. Small air leaks in the seal between the hearing protector and the skin can significantly reduce the low-frequency sound attenuation or permit a greater proportion of the low-frequency sounds to pass through. As the air leak becomes larger, attenuation lessens at all frequencies.

Material leaks. Another possible transmission pathway for sound is directly through the material of the hearing-protective device. Although the hearing-protective device can attenuate or prevent the passage of most of the sound energy, some sound is still allowed to pass through.

Vibration of the hearing-protective device. Sound can also be transmitted to the inner ear when the hearing-protective device itself is set into vibration in response to exposure to external sound energy.

Because of the flexibility of the flesh in the ear canal, earplugs can vibrate in a piston-like manner within the ear canal. This limits their low-frequency attenuation. Likewise, an earmuff cannot be attached to the head in a totally rigid manner. Its cup vibrates against the head like a mass/spring system. The muff's effectiveness is governed by the flexibility of the muff cushion and the flesh surrounding the ear, as well as by the air volume entrapped under the cup.

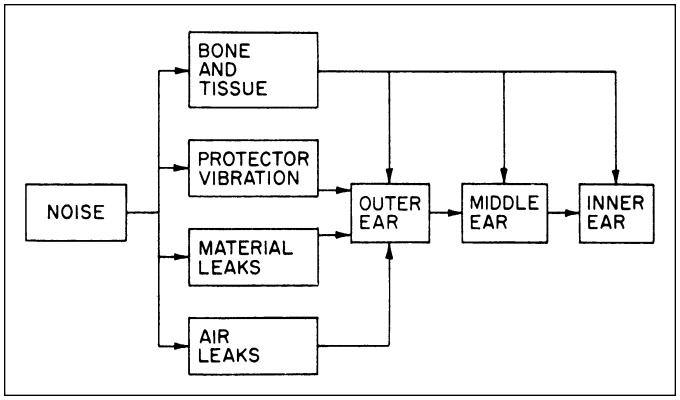


Figure 9–20. When a person is wearing a hearing protector, sound reaches the inner ear by different pathways.

Bone conduction. If the ear canal were completely closed so that no sound entered the ear by that path, some sound energy could still reach the inner ear by means of bone conduction. However, the sound reaching the inner ear by such means would be about 50 dB below the level of air-conducted sound received through the open ear canal. It is therefore obvious that no matter how the ear canal is blocked, the hearing-protective device will be bypassed by the bone-conduction pathway through the skull. A perfect hearing-protective device cannot provide more than about 50 dB of effective sound attenuation.

When a hearing-protective device is properly sized and carefully fitted and adjusted for optimum performance on a laboratory subject, air leaks are minimized, and material leaks, hearing-protective device vibration, and bone conduction are the primary sound transmission paths. In the workplace, however, this is usually not the case; sound transmission through air leaks is often the primary pathway.

All hearing protectors must be properly fitted when they are initially dispensed. Comfort, motivation, and training are also very important factors to consider if hearing protectors are to be successfully used.

CLASSES OF HEARING PROTECTION

Personal hearing-protective equipment can be divided into four classifications:

- ➢ Enclosures (entire head)
- ➢ Aural inserts, or earplugs
- ➢ Superaural protectors, or canal caps
- ➢ Circumaural protectors, or earmuffs

Enclosures. The enclosure-type hearing-protective device entirely envelops the head. A typical example is the helmet worn by an astronaut. In this case, attenuation at the ear is achieved through the acoustic properties of the helmet.

The maximum amount that a hearing protector can reduce the sound reaching the ear is from about 35 dB at 250 Hz to about 50 dB at the higher frequencies. By wearing hearing protectors and then adding a helmet that

encloses the head, an additional 10-dB reduction of sound transmitted to the ears can be achieved.

Helmets can be used to support earmuffs or earphones and cover the bony portion of the head in an attempt to reduce bone-conducted sound. Helmets are particularly well-suited for use in extremely high–noise level areas and where workers need to protect their heads from bumps or missiles. With good design and careful fitting of the seal between the edges of the helmet and the skin of the face and neck, 5–10 dB of sound attenuation can be obtained beyond that already provided by the earmuffs or earphones worn inside the helmet. This approach to protection against excessive noise is practical only in very special applications. Cost, as well as bulk, normally precludes the use of helmet-type hearing protectors in a general industrial hearing conservation program.

Aural insert protectors. Aural insert hearing-protective devices are normally called inserts or earplugs. This type of protector is generally inexpensive, but the service life is limited, ranging from single-time use to several months. Insert-type protectors or plugs are supplied in many different configurations and are made from such materials as rubber, plastics, fine glass down, foam, and wax-impregnated cotton. The pliable materials used in these aural inserts are quite soft, and there is little danger of injury resulting from accidentally forcing the plug against the tender lining of the ear canal.

It is desirable to have the employee's ears examined by qualified medical personnel before earplugs are fitted. Occasionally, the physical shape of the ear canal precludes the use of insert-type protectors. There is also the possibility that the ear canal is filled with hardened wax. If wax (cerumen) is a problem, it should be removed by qualified personnel. In some cases, the skin of the ear may be sensitive to a particular earplug material, and earplugs that do not cause an allergic response should be recommended.

Earplugs fall into three broad categories of general classification: formable, custom-molded, and premolded.

Formable earplugs (Figure 9–21) can provide good attenuation and fit any ear. Many of the formable types are designed for one-time use only, after which they are thrown away. Materials from which these disposable plugs are made include very fine glass fiber (often called Swedish wool), wax-impregnated cotton, expandable plastic, and foam.

These materials are generally rolled into a conical shape before being inserted into the ear. However, while adequate instruction must be given to emphasize the importance of a snug fit, the user must be careful not to push the material so far into the ear canal that it has to be removed by medical personnel.

One type of formable earplug is made from a plastic-like substance similar in consistency to putty. The preparation of this material requires that the individual take a quantity of it and mold or form it so that it can be inserted into the ear canal. The user should be shown the correct method of forming the material. In addition, the user must be cautioned to have clean hands when forming the material and placing it in the ear. If the hands are dirty, foreign material can get into the ear.

Custom-molded earplugs are, as the name implies, custom fit for the individual user. Generally, two or more materials (packaged separately) are mixed together to form a compound that resembles soft rubber when set. For use as a hearing-protective device, the mixture is carefully placed into the outer ear with some portion of it in the ear canal, in the manner prescribed by the manufacturer. As the material sets, it molds itself to the shape of the individual ear and external ear canal. In some cases, the materials are premixed and come in a tube from which they can be injected into the ear.

Premolded earplugs are often referred to as prefabricated, because they are usually made in large quantities in a multiple-cavity mold. The materials of construction range from soft silicone or rubber to other plastics.

There are two versions of premolded insert protector. One is known as the universal-fit type. In this type, the plug is designed to fit a wide variety of ear canal shapes and sizes. The other type of premolded protector is supplied in several different sizes to ensure a good fit (Figure 9–22). The design

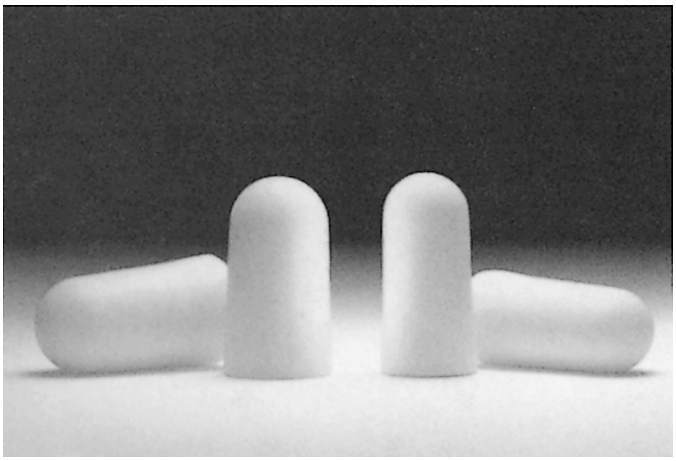


Figure 9–21. Formable earplugs. (Courtesy Cabot Safety Corp.)

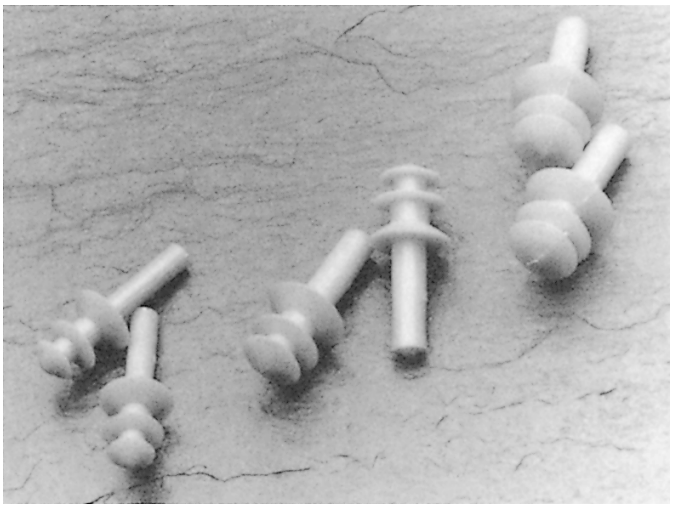


Figure 9–22. Premolded triple-flange earplugs. (Courtesy The Bilsom Group.)

of the plug is important. For example, the smooth bullet-shaped plug is very comfortable and provides adequate attenuation in straight ear canals; however, its performance falls off sharply in many irregularly shaped canals.

The use of premolded earplugs requires proper fitting by trained personnel. In many individuals, the right and left ear canals are not the same size. For this reason, properly trained personnel must prescribe the correct protector size for each ear canal. Sizing devices are available to aid in proper fitting.

The premolded type of earplug has a number of disadvantages that limit its practical acceptability. To be effective, it has to fit snugly and, for some users, this is uncomfortable. Because the plug must fit tightly and because many people have irregularly shaped ear canals, an incorrect size of plug can be selected, or the plug may not be inserted far enough, and a good fit is not obtained.

Some premolded earplugs can shrink and become hard. This is caused primarily by ear wax (present in all ear canals). The wax extracts the plasticizer from some plug materials, causing hardening and possible shrinkage of the plug. The degree of hardening and shrinkage varies from one individual user to another, depending on such factors as temperature, duration of use, and the personal hygiene of the user. Regular cleaning of the protectors with mild soap and water prolongs their useful life. To keep the plugs clean and free from contamination, most manufacturers provide a carrying case for storing the plugs when they are not in use.

Superaural protectors. Hearing-protective devices in this category (commonly known as canal caps) seal the external opening of the ear canal to achieve sound attenuation (Figure 9–23). A soft, rubberlike material is held in place by a lightweight headband. The tension of the band holds the superaural device against the external opening of the ear canal.

Circumaural protectors. Circumaural hearing-protective devices, or earmuffs, consist essentially of two cup- or dome-shaped devices that fit over the entire external ear, including the lobe, and a cushion or pad that seals against the side of the head. The ear cups are generally made of a molded rigid plastic and are lined with a cell-type foam material. The size and shape of the ear cup vary from one manufacturer to another (Figure 9–24). The cups are usually held in place by a spring-loaded suspension assembly or headband. The force applied against the head is directly related to the degree of attenuation desired. The width, circumference, and material of the earmuff cushion must be considered to maintain a proper balance of performance and comfort. To provide a good acoustic seal, the required width of the contact surface depends to a large degree on the material used in the cushion. The cup with the smallest possible circumference that can accommodate the largest ear lobes should be chosen. A slight pressure on the lobe can become painful in time, so it is very important to select a muff dome that is large enough.

The earmuffs currently on the market come with replaceable ear seals or cushions that are filled with either foam, liquid, or air—the foam-filled type is the most common. The outer covering of these seals is vinyl or a similar thermoplastic material. Human perspiration tends to extract the plasticizer from the seal material, which results in an eventual stiffening of the seals. For this reason, the seals require periodic replacement; the frequency of replacement depends on the conditions of exposure.

SELECTION OF PROTECTOR

The attenuation characteristics of a particular hearing protector must be considered before it is used for a specific applica-

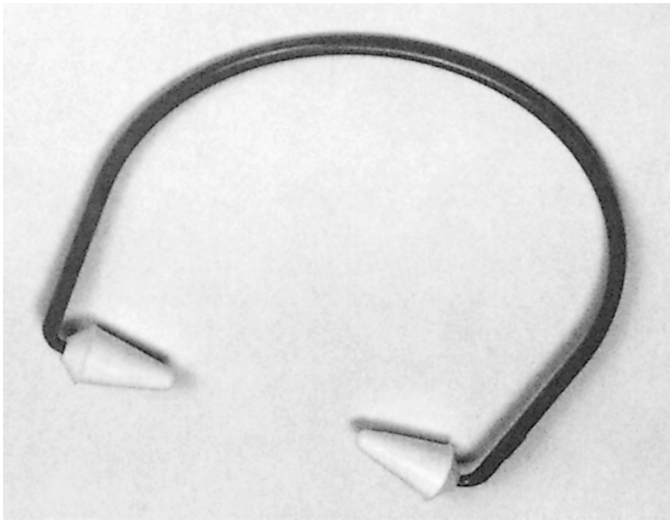


Figure 9–23. Canal caps. (Courtesy Cabot Safety Corp.)

Figure 9–24. Earmuffs. (Courtesy The Bilsom Group.)

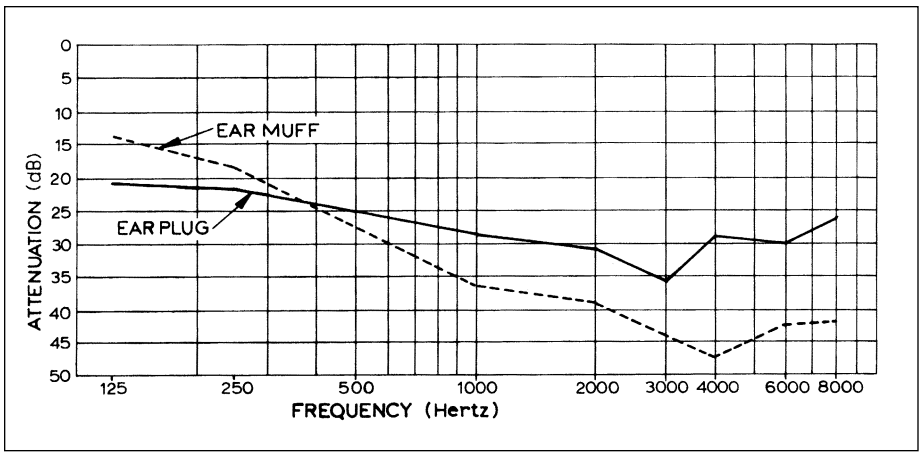


Figure 9–25. Comparison of the attenuation properties of a molded-type earplug and an earmuff protector. Note that the earplug offers greater attenuation of the lower frequencies, while the earmuff is better at the higher frequencies.

tion (Figure 9–25). As part of a well-planned hearing conservation program, characteristics of the noise levels in various areas should be known. From these data and from the attenuation information available from manufacturers, it can be determined whether a given device is suitable for the intended application. One must also consider the work area where the individual will use the hearing-protective device. For example, a large-volume earmuff would not be practical for an individual who must work in confined areas where there is very little head clearance. In such instances, a very small or flat ear cup or insert-type protector would be more practical.

When using muff-type protectors in special hazard areas (such as power-generating stations where there are electrical hazards), it may be desirable to use nonconductive suspension systems with muff-type protectors. Also, if other personal protective equipment such as safety hats or safety spectacles must be worn, the degree of hearing protection required must not be compromised. The efficiency of muff type protectors is reduced when they are worn over the frames of eye-protective devices. In these cases, the amount of reduction in noise attenuation depends on the type of glasses being worn as well as the size and shape of the individual wearer's head. When eye-protective devices are required, it is recommended that ones with cable-type temples be used, because they create the smallest possible opening between the seal and the head.

When selecting a hearing-protective device, one should also consider how often a worker is exposed to excessive noise. If exposure is relatively rare (once a day or once a week), an insert or plug device will probably satisfy the requirement. On the other hand, if the noise exposure is relatively frequent and the employee must wear the protective device for an extended period of time, the muff-type protector might be preferable. If the noise exposure is intermittent, the muff-type protector is probably more desirable, because it is somewhat more difficult to remove and reinsert earplugs.

When determining the suitability of a hearing-protective device for a given application, the manufacturer's reported test data must be examined carefully. It is necessary to correlate that information with the specific noise exposure the device is intended to control. The manufacturer should provide attenuation characteristics of the individual hearing-protective devices over a range of frequencies.

The most convenient method by which to gauge the adequacy of a hearing protector's attenuation capacity is to check its Noise Reduction Rating (NRR), a rating that was developed by the EPA (U.S. Environmental Protection Agency). According to the EPA regulation, the NRR must be printed on the hearing protector's package. The NRR can be correlated with an individual worker's noise environment to assess the adequacy of the attenuation characteristics of the particular hearing-protective device. Appendix B of 29 *CFR* 1910.95 describes methods of using the NRR to determine whether a particular hearing-protective device (HPD) provides adequate protection within a given exposure environment. It must be noted, however, that NRRs are based on data obtained under laboratory conditions using trained listeners who are fitted by professionals. Their ratings differ significantly from what is achieved in the real world. In 1998, NIOSH published *Occupational Noise Exposure, Revised Criteria.* Based on studies conducted by numerous researchers of real world NRRs achieved by 84% of wearers in 20 independent studies, they recommend lowering the manufacturer's NRRs significantly. NIOSH recommended using subject fit data based on ANSI S12.6-1997 to estimate HPD attenuation. If this is not available, they recommend that the labeled NRRs be de-rated as follows:

- ➢ Earmuffs—subtract 25 percent from the manufacturer's labeled NRR
- ➢ Formable earplugs—subtract 50 percent from the manufacturer's NRR
- ➢ All other plugs—subtract 70 percent from the manufacturer's NRR

(See Bibliography, NIOSH, 1998.)

INDUSTRIAL AUDIOMETRY

Audiometry, or the measurement of hearing, is central to industrial hearing conservation programs because all follow-up activities and program evaluations are based on such test results. Briefly, the objectives in industrial audiometry are as follows:

- ➢ Obtain a baseline audiogram that indicates an individual's hearing ability at the time of the preplacement examination.
- ➢ Provide a record of an employee's hearing acuity.
- ➢ Check the effectiveness of noise-control measures by measuring the hearing thresholds of exposed employees.
- ➢ Record significant hearing threshold shifts in exposed employees during the course of their employment.
- ➢ Comply with government regulations.

An audiometer is required to help assess an individual's hearing ability. An audiometer is an electronic instrument that converts electrical energy into sound energy in precisely variable amounts. It should meet the standards set forth in ANSI S3.6–1996, *Specifications for Audiometers*.

An audiometer consists of an oscillator, which produces pure tones at predetermined frequencies; an attenuator, which controls the intensity of the sound or tone produced; a presenter switch; and earphones, through which the person whose hearing is being tested hears the tone.

Threshold Audiometry

Threshold audiometry is used to determine an employee's auditory threshold for a given stimulus. Measurements of hearing are made to determine hearing acuity and to detect abnormal function in the ear. Before hearing can be described as abnormal, a reference point, or normal value, must be designated.

The quantity that is of interest, however, is not the sound pressure level of the normal hearing threshold, but rather the magnitude of departure from a standard reference threshold. Levels that depart from the norm can be easily detected by their divergence from the reference threshold, which shows up directly on the audiometer attenuator dial.

Hearing threshold levels are those intensities at specific frequencies at which a sound or a tone can just barely be heard. The term *air conduction* refers to the air path by which the test sounds generated at the earphones are conducted through air to stimulate the eardrum.

The record of measured hearing thresholds is called a threshold audiogram. Audiometric tests can also be recorded in the form of audiograms, on which are plotted both sound intensity (in dB) and frequency (in Hz). A sample audiogram is shown in Figure 9–26.

Who Should Be Examined

Preplacement hearing-threshold tests should be taken by all job applicants, not just those who are to work in noisy areas. This establishes a baseline hearing threshold for each employee for future comparison. Preplacement hearing tests are essential if a company is to protect itself from liability for preexisting hearing loss incurred elsewhere. If an employee is hired with hearing damage and he or she is subsequently exposed to high noise levels, the company may be liable for all the employee's hearing loss—unless it can be proved that the employee had a preexisting hearing loss when hired. In some states, the most recent employer is liable for all compensable hearing loss, regardless of past exposures.

Periodic follow-up hearing tests should be administered to persons stationed in areas where noise exposures exceed permissible levels.

The schedule for periodic follow-up hearing tests depends largely on an employee's noise exposure. Assuming that a record of the worker's hearing status was established at the time of employment or placement, the first reexamination should be made 9–12 months after placement. If no significant threshold shifts relative to the preplacement audiogram are noted, subsequent follow-up tests can be administered at yearly intervals. If the noise exposure is relatively low, the interval between follow-up tests can be increased. This decision should be based on the combination of the conditions of the exposure and the results of previous audiograms and clinical examinations.

Noise exposure is by no means the only reason for a change in an individual's audiogram. When a change in hearing status is confirmed, its cause must be determined. Improper placement of earphones and excessive ambient noise in the test room can affect audiogram results. Physiological changes as a result of the employee's age and state of health can also affect audiogram results. The individual's motivation and attitude toward the test can affect performance.

An industrial audiometric program can identify people who are experiencing hearing threshold changes that are not related to noise exposure on the job. These workers should be referred to their family physician for diagnosis and treatment. However, when threshold shifts related to noise exposure are identified, this procedure should be followed:

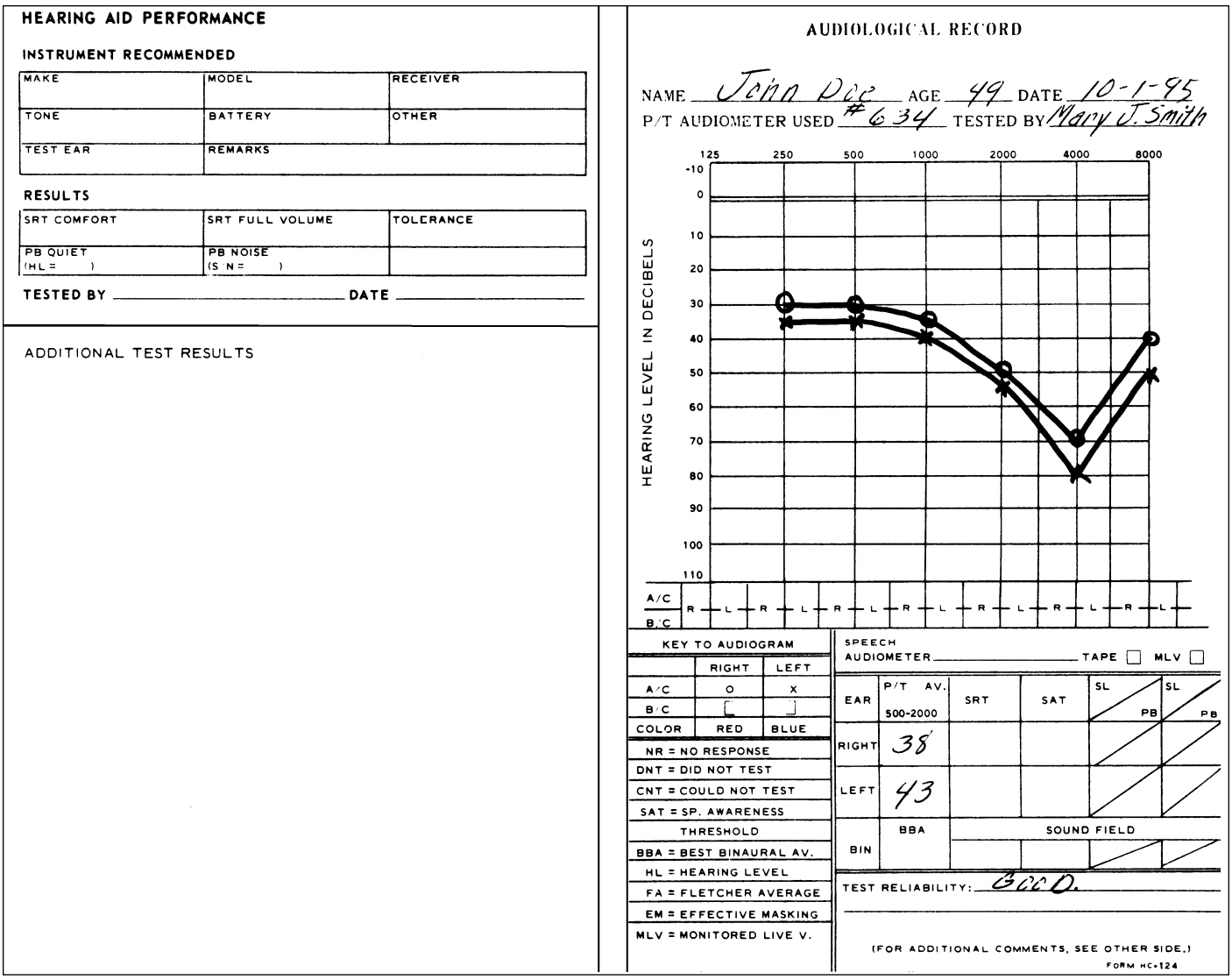
1. Check the fit of the hearing-protective device, if one is worn by the worker.
2. Repeat or initiate educational sessions to encourage the employee to wear a hearing-protective device, if it has not been worn.
3. Investigate the noise levels in the work area, particularly if a previous sound level survey failed to reveal noise hazards.

Noise exposure information, correlated with audiometric test results, is necessary to make intelligent decisions about a firm's hearing conservation program. If all hearing tests and medical opinion point to a progressive deterioration of an individual's hearing, the safety and health professional should provide and enforce the use of hearing-protection equipment and/or recommend that the individual's exposure to excessive noise be controlled.

Conclusions about the general noise environment should not be based on changes in the hearing of a single individual, because the variation in individual susceptibility to noise is broad. Conclusions can, however, be drawn from the average changes—or lack of them—in a group of employees exposed to the same noise environment.

Effective Programs

An effective industrial audiometric program should include consideration of the following components:



HEARING AID PERFORMANCE

INSTRUMENT RECOMMENDED

MAKE	MODEL	RECEIVER
TONE	BATTERY	OTHER
TEST EAR	REMARKS	

RESULTS

SRT COMFORT	SRT FULL VOLUME	TOLERANCE
PB QUIET (HL =)	PB NOISE (S/N =)	

TESTED BY _____ DATE _____

ADDITIONAL TEST RESULTS

AUDIOLOGICAL RECORD

NAME John Doe AGE 49 DATE 10-1-95

P/T AUDIOMETER USED #634 TESTED BY Mary J. Smith

KEY TO AUDIOGRAM	RIGHT	LEFT
A/C	O	X
B/C	[	]
COLOR	RED	BLUE

NR = NO RESPONSE
DNT = DID NOT TEST
CNT = COULD NOT TEST
SAT = SP. AWARENESS THRESHOLD
BBA = BEST BINAURAL AV.
HL = HEARING LEVEL
FA = FLETCHER AVERAGE
EM = EFFECTIVE MASKING
MLV = MONITORED LIVE V.

SPEECH AUDIOMETER _____ TAPE ☐ MLV ☐

EAR	P/T AV. 500-2000	SRT	SAT	SL PB	SL PB
RIGHT	38				
LEFT	43				
BIN	BBA	SOUND FIELD			

TEST RELIABILITY: Good.

(FOR ADDITIONAL COMMENTS, SEE OTHER SIDE.)

FORM HC-124

Figure 9–26. This audiogram shows the initial effects of exposure to excessive noise. Note the decided notch at the 4,000-Hz frequency.

- ➢ Medical surveillance
- ➢ Qualified personnel
- ➢ Suitable test environment
- ➢ Calibrated equipment
- ➢ Adequate record keeping

MEDICAL SURVEILLANCE

Medical surveillance is essential in a hearing-testing program so that the program can fulfill its dual purpose of detecting hearing loss and providing valid records for compensation claims. Although many smaller companies do not have a medical department, they can satisfy the general medical surveillance requirement by using part-time medical consultants.

Noise-susceptible workers are employees who suffer handicapping hearing losses more quickly than do their colleagues under equivalent noise exposures. These workers constitute the group from whom compensation claims are most likely to arise and for whom the risk of hearing damage is likely to be greatest.

During the preplacement examination, the applicant should provide a detailed history covering his or her prior occupational experience and a personal record of illnesses and injuries. For applicants who will work in noisy environments, the history should include noise exposures in previous jobs, including any in the military services. The medical phase of the history should detail frequency of earache, ear discharge, ear injury, surgery (ear or mastoid), head injury with unconsciousness, ringing in the ears, hearing loss in the immediate family, the use of drugs, and history of allergy and toxic exposures. A standard form can be created for this purpose.

QUALIFIED PERSONNEL

Audiometric tests should be administered by a qualified individual such as a specially trained nurse, an audiologist, or an occupational hearing conservationist. An occupational hearing conservationist (OHC) is an individual who has satisfactorily completed a course of training that meets, as a

minimum, the guidelines established by the Council for Accreditation in Occupational Hearing Conservation.

The duties of the OHC are to perform baseline and periodic pure-tone air-conduction threshold tests. Systematic supervision and encouragement of the OHC by the physician, audiologist, or other qualified person in charge of the audiometric program is recommended to maintain the high motivation required for proper audiometric testing. The supervision should include periodic review of the testing procedures used by the audiometric technician to make sure that they conform to established procedures.

SUITABLE TEST ENVIRONMENT

Hearing measurements must be made in a test room or booth that conforms to the requirements established by ANSI S3.1–1991 (R1999), *Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms*. It must be sufficiently quiet within the enclosure so that external noises do not interfere with the employee's perception of the test sounds. This usually requires a special sound-treated enclosure (Figure 9–27).

Hearing-testing rooms should be located away from outside walls, elevators, and locations with heating and plumbing noises. If the background noise levels in the test area do not exceed the sound levels allowed by the standard, the background noise does not affect the hearing test results. The hearing test booth or room can be either a prefabricated unit or one that is built on the premises. Doors, gaskets, and other parts of the room or booth that can deteriorate, warp, or crack should be carefully inspected periodically.

Figure 9–27. Sound booth audiometric testing. (Courtesy Tremetrics Occupational Health Group.)

In addition to proper acoustical standards, the booth or room should allow for ease of access and egress and be provided with good, comfortable ventilation and lighting. The audiometric technician should be able to sit outside the room or booth but be able to see the interior of the room through a window.

To select the proper room, it is necessary to conduct a noise survey at the proposed test location. Noise levels at each test frequency should be measured and recorded using an octave-band sound level meter. The audiometric booth selected must have sufficient noise attenuation so that the background noise levels present at each test frequency are reduced and do not exceed the maximum permissible background levels listed in the current ANSI standard.

CALIBRATED EQUIPMENT

Limited-range, pure-tone audiometers must conform to the current ANSI standard listed in *Specifications for Audiometers*. Two basic types of audiometers are available: automatic recording audiometers and manually operated audiometers.

The audiometer should be subjected to a biological check each day before the instrument is used. The biological check is done by testing the hearing of a person whose hearing threshold is known and stable. The check should include the movement and bending of cords and wires, knob turning, switch actuating, and button pushing to make sure that no sounds are produced in the earphones other than the test tones.

An exhaustive electronic calibration of the audiometric test instrument should be made annually by a repair and calibration facility that has the specialized equipment and skilled technical personnel necessary for this work. A certificate of calibration should be kept with the audiometer at all times.

ADEQUATE RECORDS

The medical form used in audiometric testing programs should include all basic data related to the hearing evaluation. Hearing threshold values, noise-exposure history, and pertinent medical history should be accurately recorded each time an employee's hearing is tested. The employee should be identified by name, social security number, sex, and age. Additional information such as the date and time of the test (day of the week, time of day), conditions under which the test was performed, and the name of the examiner should also be included.

Audiometric test records for an employee should be kept for at least the duration of employment. The records could become the basis for a settlement of a hearing loss claim.

Periodic audiograms are a profile of the employee's hearing acuity. Any change from the results of previous audiograms should be investigated. One possible reason for a

hearing loss is that the employee's hearing protectors are inadequate or improperly worn.

The audiometric testing program should be both practical and feasible. In small companies, where the total number of employees to be tested is small, it would be impractical to purchase a booth and audiometer. It would be more economical to consider a mobile audiometer testing service or to refer the employees to a local, properly equipped and staffed hearing center or to a qualified physician or audiologist for an audiometric examination.

Audiometric testing is an integral part of a comprehensive hearing conservation program. The OSHA Hearing Conservation Standard discussed in the following section details specific requirements for audiometric testing and other required components of an effective hearing conservation program.

NOISE-EXPOSURE REGULATIONS

Background

The federal regulation of occupational noise exposure started with the rules issued by the Bureau of Labor Standards under the authority of the Walsh–Healey Public Contracts Act. These rules required that occupational noise exposure be reasonably controlled to minimize fatigue and the probability of accidents. The federal occupational noise-exposure regulations were originally written to apply only to contractors under the Walsh–Healey Public Contracts Act and the McNamara–O'Hara Service Contracts Act. Under the Williams–Steiger Occupational Safety and Health Act of 1970, the Bureau of Labor Standards was replaced by the Occupational Safety and Health Administration (OSHA).

The National Institute for Occupational Safety and Health (NIOSH) was established within the Department of Health and Human Services (formerly the Department of Health, Education and Welfare) by the Occupational Safety and Health Act of 1970 to conduct research and to recommend new occupational safety and health standards. The recommendations are transmitted to the Department of Labor, which is responsible for the final setting, promulgation, and enforcement of the standards.

In 1972, NIOSH provided the Department of Labor with a document called *Criteria for a Recommended Standard: Occupational Exposure to Noise*. Subsequently, the assistant secretary of labor determined that a standard advisory committee on noise should be formed. The purpose of this OSHA Advisory Committee was to obtain and evaluate additional recommendations from labor, management, government, and independent experts. The committee considered written and oral comments directed to it by interested parties. The committee then transmitted its recommendations for a revised standard to OSHA on December 20, 1973.

In 1974, OSHA published a proposed standard in the *Federal Register* that limited an employee's exposure level to 90 dBA, calculated as an eight-hour, time-weighted average (TWA). NIOSH commented on OSHA's proposed standard, stating that there was a need for reducing the eight-hour exposure level to 85 dBA. However, NIOSH was unable to recommend a specific future date after which the 85-dBA noise level should become mandatory for all industries. Sufficient data were not available to demonstrate the technological feasibility of this level.

The EPA reviewed the OSHA proposal and recommended that the limit not exceed 85 dBA. They reviewed the proposed noise standard and recommended that additional studies be undertaken to explore the efficacy of reducing the permissible level still further at some future date. The proposed revisions to the OSHA rules for occupational noise exposure were published in the *Federal Register* on October 24, 1974.

After years of collecting oral and written public testimony, which resulted in an unwieldy public record of almost 40,000 pages, OSHA promulgated revisions for the noise standard (46 *FR* 4078) in January 1981. These revisions were followed by deferrals, stays (46 *FR* 42622), further revisions, further public hearings, and a multiplicity of lawsuits, all of which culminated in the promulgation of a hearing conservation amendment (48 *FR* 9738) on March 8, 1983, with an effective date of April 7, 1983.

It was estimated by OSHA (46 *FR* 4078) that there were 2.9 million workers in American production industries who experience eight-hour noise exposures exceeding 90 dBA. An additional 2.3 million experience exposure levels in excess of 85 dBA. The Hearing Conservation Amendment (HCA) applies to all those employees with noise exposures ≥ 85 dBA except for those in oil and gas well drilling and servicing industries, which are specifically exempted. Additionally, the Amendment does not apply to those engaged in construction or agriculture, although a Construction Industry Noise Standard exists (29 *CFR* 1926.52 and 1926.101). This standard is essentially identical to paragraphs (a) and (b) of the General Industry Noise Standard.

The OSHA Noise Standard

Prior to promulgation of the HCA the existing Noise Standard (29 *CFR* 1910.95[a] and [b]) established a permissible noise-exposure level of 90 dBA for 8 hours and required the employer to reduce exposure to that level by use of feasible engineering and administrative controls. In all cases in which sound levels exceeded the permissible exposure, regardless of the use of hearing-protective devices, "a continuing, effective hearing conservation program" was required. However, the details of such a program were never mandated. Paragraphs (c) through (p) of the HCA replaced paragraph (b)(3) of 29 *CFR* 1910.95 and supplemented OSHA's definition of an "effective hearing conservation program."

Hearing Conservation Programs

An effective hearing conservation program prevents hearing impairment as a result of noise exposure on the job. In terms

of existing workers' compensation laws, an effective hearing conservation program is one that limits the amount of compensable hearing loss in the frequency range over which normal hearing is necessary for communication. It should be noted that "compensable" loss at present does not include frequencies over 4,000 Hz, although such loss impairs enjoyment of sound and may interfere with speech discrimination. In compliance with the OSHA requirements, an effective hearing conservation program must be instituted if any employee's noise exposure exceeds current limits as defined in the OSHA Noise Exposure Standard 29 *CFR* 1910.95.

All employees whose noise exposures equal or exceed an 8-hour TWA of 85 dBA must be included in a hearing conservation program comprised of five basic components: exposure monitoring, audiometric testing, hearing protection, employee training, and record keeping. Note that although the 8-hour TWA permissible exposure remains 90 dBA, a hearing conservation program becomes mandatory at an 8-hour TWA exposure of 85 dBA.

The following summary briefly discusses the required components of the hearing conservation program.

Monitoring. The HCA requires employers to monitor employee noise-exposure levels in a manner that can accurately identify employees who are exposed at or above an 8-hour TWA exposure of 85 dBA. The exposure measurement must include all noise within an 80–130-dBA range. The requirement is performance oriented and allows employers to choose the monitoring method that best suits each situation.

Employees are entitled to observe monitoring procedures, and, in addition, they must be notified of the results of exposure monitoring. However, the method used to notify employees is left to the discretion of the employer.

Employers must remonitor workers' exposures whenever changes in exposures are sufficient to require new hearing protectors or whenever employees not previously included, because they were not exposed to an 8-hour TWA of 85 dBA, are included in the program.

Instruments used for monitoring employee exposures must be calibrated to ensure that the measurements are accurate. Because calibration procedures are unique to each instrument, employers should follow the manufacturer's instructions to determine when and how extensively to calibrate.

AUDIOMETRIC TESTING

Audiometric testing not only monitors employee hearing acuity over time but also provides an opportunity for employers to educate employees about their hearing and the need to protect it. The audiometric testing program includes obtaining baseline and annual audiograms and initiating training and follow-up procedures. The audiometric testing program should indicate whether hearing loss is being prevented by the employer's hearing conservation program. Audiometric testing must be made available to all employees who have time-weighted average–exposure levels of 85 dBA. A professional (audiologist, otolaryngologist, or physician) must be responsible for the program, but need not be present when a qualified occupational hearing conservationist is actually conducting the testing. Professional responsibilities include overseeing the program and the work of the OHCs, reviewing problem audiograms, and determining whether referral is necessary. Either a professional or an OHC can conduct audiometric testing. In addition to administering audiometric tests, the tester (or the supervising professional) is also responsible for ensuring that the tests are conducted in an appropriate test environment, for seeing that the audiometer works properly, for reviewing audiograms for standard threshold shifts (as defined in the HCA), and for identifying audiograms that require further evaluation by a professional.

Audiograms. There are two types of audiograms required in the hearing conservation program: baseline and annual audiograms. The baseline audiogram is the reference audiogram against which subsequent audiograms are compared. Baseline audiograms must be provided within six months of an employee's first exposure at or above a TWA of 85 dBA. However, when employers use mobile test vans to do audiograms, they have up to one year after an employee's first exposure to workplace noise at or above a TWA of 85 dBA to obtain the baseline audiogram. Additionally, when mobile vans are used and employers are allowed to delay baseline testing for up to a year, those employees exposed to time-weighted average levels of 85 dBA or more must be issued and fitted with hearing protectors six months after their first exposure. The hearing protectors are to be worn until the baseline audiogram is obtained. Baseline audiograms taken before the effective date of the amendment are acceptable as baselines in the program if the professional supervisor determines that the audiogram is valid. The annual audiogram must be conducted within one year of the baseline. It is important to test hearing on an annual basis to identify changes in hearing acuity so that protective follow-up measures can be initiated before hearing loss progresses.

Audiogram evaluation. Annual audiograms must be routinely compared to baseline audiograms to determine whether the audiogram is accurate and whether the employee has lost hearing ability; that is, to determine whether a standard threshold shift, or STS, has occurred. An effective program depends on a uniform definition of an STS. An STS is defined in the amendment as an average shift (or loss) in either ear of 10 dB or more at the 2,000-, 3,000-, and 4,000-Hz frequencies. A method of determining an STS by computing an average was chosen because it diminishes the number of persons identified as having an STS who are later shown not to have had a significant change in hearing ability.

Example 7

An example of computing the STS is shown in Table 9–F. Considering the values for 2,000, 3,000, and 4,000 Hz, there are changes in hearing threshold of 10, 15, and 25 dB, respectively. Thus,

$$\text{STS} + \frac{(10 + 15 + 25)}{3} = \frac{50}{3} = 16.7 \text{ dB} \qquad (25)$$

Conclusion— Example 7

The STS is +16.7 dB; hearing has deteriorated; the employee must be notified in writing within 21 days; and, depending on professional discretion, the employer can elect to revise the baseline.

If an STS is identified, the employee must be fitted or refitted with adequate hearing protectors, shown how to use them, and required to wear them. In addition, employees must be notified within 21 days from the time the determination is made that their audiometric test results indicate an STS. Some employees with an STS should be referred for further testing if the professional determines that their test results are questionable or if they have an ear problem of a medical nature caused or aggravated by wearing hearing protectors. If the suspected medical problem is not thought to be related to wearing protectors, employees must merely be informed that they should see a physician. If subsequent audiometric tests show that the STS identified on a previous audiogram is not persistent, employees exposed to a TWA of less than 90 dBA can discontinue wearing hearing protectors.

A subsequent audiogram can be substituted for the original baseline audiogram if the professional supervising the program determines that the employee has experienced a persistent STS. The substituted audiogram becomes known as the revised baseline audiogram. This substitution ensures that the same shift is not repeatedly identified. The professional may also decide to revise the baseline audiogram after an improvement in hearing has occurred, which ensures that the baseline reflects actual thresholds as much as is possible. When a baseline audiogram is revised, the employer must, of course, also retain the original audiogram. To obtain valid audiograms, audiometers must be used, maintained, and calibrated according to specifications detailed in appendices C and E of the standard.

HEARING PROTECTORS

Hearing protectors must be made available to all workers exposed at or above a TWA of 85 dBA. This requirement ensures that employees have access to protectors before they experience a loss in hearing. When baseline audiograms are delayed because it is inconvenient for mobile test vans to visit the workplace more than once a year, protectors must be worn by employees for any period exceeding six months from the time they are first exposed to 8-hour average noise levels of 85 dBA or above until their baseline audiograms are obtained. The use of hearing protectors is also mandatory for employees who have experienced threshold shifts, because these workers are particularly susceptible to noise.

Table 9–F. ***Computing the Standard Threshold Shift (STS)***

Frequency (Hz)	Baseline Audiogram Threshold (dB)	Annual Audiogram Threshold (dB)	Change
500	5	5	0
1,000	5	5	0
2,000	0	10	+10
3,000	5	20	+15
4,000	10	35	+25
6,000	10	15	+5

With the help of a person who is trained in fitting hearing protectors, employees should decide which size and type protector is most suitable for their working environment. The protector selected should be comfortable to wear and offer sufficient attenuation to prevent hearing loss. Employees must be shown how to use and care for their protectors, and they must be supervised on the job to ensure that they continue to wear them correctly.

Hearing protectors must provide adequate attenuation in each employee's work environment. The employer must reevaluate the suitability of an employee's present protector whenever there is a change in working conditions that might render the hearing protector inadequate. If workplace noise levels increase, employees must be given more effective protectors. The protector must reduce the level of exposure to at least as low as 90 dBA, or to 85 dBA or below when an STS has occurred.

TRAINING

Employee training is important because when workers understand the hearing conservation program's requirements and why it is necessary to protect their hearing, they are better motivated to actively participate in the program. They are more willing to cooperate by wearing their protectors and by undergoing audiometric tests. Employees exposed to TWAs of 85 dBA and above must be trained at least annually in the following: the effects of noise; the purpose, advantages, disadvantages, and attenuation characteristics of various types of hearing protectors; the selection, fitting, and care of protectors; and the purpose and procedures of audiometric testing. Training does not have to be accomplished in one session. The program can be structured in any format, and different individuals can conduct different parts as long as the required topics are covered. For example, audiometric procedures could be discussed immediately before audiometric testing. The training requirements are such that employees must be reminded on a yearly basis that noise is hazardous to hearing, and that they can prevent damage by wearing a hearing protector, where appropriate, and by participating in audiometric testing.

Table 9–G. ***Comparison of OSHA's PEL for Noise with NIOSH/ACGIH Recommendations.***

Sound Level (dBA)	*Duration per Day (hours)*	
	OSHA	*NIOSH/ACGIH*
85	16	8
88	10.6	4
90	8	2.5
91	7	2
94	4.6	1
95	4	47 min
97	3	30 min
100	2	15 min

Source: *Occupational Noise Exposure, Revised Criteria,* NIOSH, 1998.

RECORD KEEPING

Records of noise-exposure measurement must be kept for two years. It may be prudent, however, to keep these records for a longer time in accordance with other medical records requirements under OSHA. Records of audiometric test results must be maintained for the duration of the affected employee's employment. Audiometric test records must include the name and job classification of the employee, the date the test was performed, the examiner's name, the date of acoustic or exhaustive calibration, measurements of the background sound pressure levels in audiometric test rooms, and the employee's most recent noise-exposure measurement.

NIOSH and ACGIH Noise Exposure Guidelines

As stated above, both NIOSH and the EPA recommended to OSHA that the eight-hour TWA for noise be reduced to 85 dBA. In 1998, NIOSH issued *Occupational Noise Exposure, Revised Criteria*. In this document NIOSH revised its 1972 recommendation, going beyond attempts to conserve hearing by focusing on prevention of noise induced hearing loss. They continued to recommend an eight-hour TWA of 85 dBA. However, they recommended switching from a 5 dB exchange rate to a 3-dB exchange rate, as they believed that current scientific evidence supported this change. This 3-dB doubling rate is used by ACGIH in their TLV (see Appendix B).

NIOSH also recommended a new criterion for the definition of significant threshold shifts (STS). Instead of OSHA's definition of a STS as a 10-dB loss in either ear averaged over the frequencies of 2000, 3000, and 4000Hz, NIOSH recommended defining a STS as a 15-dB loss in either ear at any of these frequencies—500, 1,000, 2,000, 3,000, 4,000, or 6,000 Hz. This loss is as determined by two consecutive tests.

The use of Age Correction Factors, which are in the OSHA standard, Appendix F, have been dropped by NIOSH in the 1998 revised criteria. Finally, as mentioned in the previous section on NRRs, NIOSH recommended significant reductions in the NRRs of hearing protectors.

Both NIOSH and ACGIH recommend an 8-hour TWA of 85 dBA, with a 3-dB exchange rate, while OSHA's eight-hour TWA is 90 dBA with a 5-dB exchange rate. Table 9–G compares the NIOSH REL and ACGIH TLV for noise exposure with OSHA's noise standard. As the noise level increases, there are significant differences in allowable exposure between the current OSHA standard and the NIOSH/ACGIH recommendations.

SUMMARY

Because industrial noise problems are extremely complex, there is no one "standard" program that is applicable to all situations. In order to protect the hearing of employees and to avoid compensation costs, it behooves industry to consider and evaluate its noise problems and to take steps toward the establishment of effective hearing conservation procedures. The OSHA regulations require the control of noise exposures, employee protection against the effects of noise exposures, and the initiation of comprehensive and effective hearing conservation programs.

As outlined in this chapter, an effective hearing conservation program consists of the following:

- ➢ Noise measurement and analysis
- ➢ Engineering control of noise exceeding permissible levels
- ➢ Hearing protection for those employees working in areas where noise cannot be feasibly controlled
- ➢ Audiometric examinations for all employees
- ➢ Employee training
- ➢ Record keeping

The effectiveness of a hearing conservation program depends on the cooperation of employers, supervisors, employees, and others concerned. Management's responsibility in this type of program includes taking noise measurements, initiating noise-control measures, undertaking the audiometric testing of employees, providing hearing-protective equipment where it is required, enforcing the use of such protective equipment with sound policies and by example, and informing employees of the benefits to be derived from a hearing conservation program.

It is the employee's responsibility to make proper use of the protective equipment provided by management. It is also the employee's responsibility to observe any rules or regulations in the use of equipment designed to minimize noise exposure.

Detailed references to noise and its management, effects, and control can be found in a great many books and periodicals. For those companies needing assistance in establishing hearing conservation programs, consultation services are available in a number of professional areas through private consultation, insurance, and governmental groups.

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1910.95—OCCUPATIONAL NOISE EXPOSURE

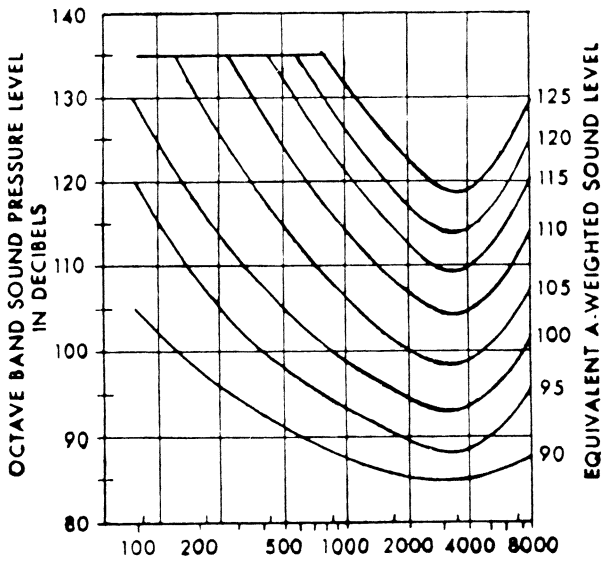
(a) Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table G–16 when measured on the A scale of a standard sound level meter at slow response. When noise levels are determined by octave band analysis, the equivalent A-weighted sound level may be determined as follows:

TABLE G–16—PERMISSIBLE NOISE EXPOSURES [1]

Duration per day, hours	*Sound level dBA slow response*
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

[1]When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: $C_1/T_1 + C_2/T_2 \ldots C_n/T_n$ exceeds unity, then, the mixed exposure should be considered to exceed the limit value. C_n indicates the total time of exposure at a specified noise level, and T_n indicates the total time of exposure permitted at that level.

Figure G-9



Equivalent sound level contours. Octave band sound pressure levels may be converted to the equivalent A-weighted sound level by plotting them on this graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits from Table G–16.

(b)

(1) When employees are subjected to sound exceeding those listed in Table G–16, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of Table G–16, personal protective equipment shall be provided and used to reduce sound levels within the levels of the table.

Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

(2) If the variations in noise level involve maxima at intervals of 1 second or less, it is to be considered continuous.

(c) Hearing conservation program.

(1) The employer shall administer a continuing, effective hearing conservation program, as described in paragraphs (c) through (o) of this section, whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level (TWA) of 85 decibels measured on the A scale (slow response) or, equivalently, a dose of fifty percent. For purposes of the hearing conservation program, employee noise exposures shall be computed in accordance with Appendix A and Table G–16a, and without regard to any attenuation provided by the use of personal protective equipment.

(2) For purposes of paragraphs (c) through (n) of this section, an 8-hour time-weighted average of 85 decibels or a dose of fifty percent shall also be referred to as the action level.

(d) Monitoring.

(1) When information indicates that any employee's exposure may equal or exceed an 8-

hour time-weighted average of 85 decibels, the employer shall develop and implement a monitoring program.

(i) The sampling strategy shall be designed to identify employees for inclusion in the hearing conservation program and to enable the proper selection of hearing protectors.

(ii) Where circumstances such as high worker mobility, significant variations in sound level, or a significant component of impulse noise make area monitoring generally inappropriate, the employer shall use representative personal sampling to comply with the monitoring requirements of this paragraph unless the employer can show that area sampling produces equivalent results.

(2)

(i) All continuous, intermittent and impulsive sound levels from 80 decibels to 130 decibels shall be integrated into the noise measurements.

(ii) Instruments used to measure employee noise exposure shall be calibrated to ensure measurement accuracy.

(3) Monitoring shall be repeated whenever a change in production, process, equipment or controls increases noise exposures to the extent that:

(i) Additional employees may be exposed at or above the action level; or

(ii) The attenuation provided by hearing protectors being used by employees may be rendered inadequate to meet the requirements of paragraph (j) of this section.

(e) Employee notification. The employer shall notify each employee exposed at or above an 8-hour time-weighted average of 85 decibels of the results of the monitoring.

(f) Observation of monitoring. The employer shall provide affected employees or their representatives with an opportunity to observe any noise measurements conducted pursuant to this section.

(g) Audiometric testing program.

(1) The employer shall establish and maintain an audiometric testing program as provided in this paragraph by making audiometric testing available to all employees whose exposures equal or exceed an 8-hour time-weighted average of 85 decibels.

(2) The program shall be provided at no cost to employees.

(3) Audiometric tests shall be performed by a licensed or certified audiologist, otolaryngologist, or other physician, or by a technician who is certified by the Council of Accreditation in Occupational Hearing Conservation, or who has satisfactorily demonstrated competence in administering audiometric examinations, obtaining valid audiograms, and properly using, maintaining and checking calibration and proper functioning of the audiometers being used. A technician who operates microprocessor audiometers does not need to be certified. A technician who performs audiometric tests must be responsible to an audiologist, otolaryngologist or physician.

(4) All audiograms obtained pursuant to this section shall meet the requirements of Appendix C: *Audiometric Measuring Instruments.*

(5) Baseline audiogram.

(i) Within 6 months of an employee's first exposure at or above the action level, the employer shall establish a valid baseline audiogram against which subsequent audiograms can be compared.

(ii) **Mobile test van exception.** Where mobile test vans are used to meet the audiometric testing obligations, the employer shall obtain a valid baseline audiogram within 1 year of an employee's first exposure at or above the action level. Where baseline audiograms are obtained more than 6 months after the employee's first exposure at or above the action level, employees shall wear hearing protectors for any period exceeding six months after first exposure until the baseline audiogram is obtained.

(iii) Testing to establish a baseline audiogram shall be preceded by at least 14 hours without exposure to workplace noise. Hearing protectors may be used as a substitute for the requirement that baseline audiograms be preceded by 14 hours without exposure to workplace noise.

(iv) The employer shall notify employees of the need to avoid high levels of non-occupa-

tional noise exposure during the 14-hour period immediately preceding the audiometric examination.

(6) Annual audiogram. At least annually after obtaining the baseline audiogram, the employer shall obtain a new audiogram for each employee exposed at or above an 8-hour time-weighted average of 85 decibels.

(7) Evaluation of audiogram.

(i) Each employee's annual audiogram shall be compared to that employee's baseline audiogram to determine if the audiogram is valid and if a standard threshold shift as defined in paragraph (g)(10) of this section has occurred. This comparison may be done by a technician.

(ii) If the annual audiogram shows that an employee has suffered a standard threshold shift, the employer may obtain a retest within 30 days and consider the results of the retest as the annual audiogram.

(iii) The audiologist, otolaryngologist, or physician shall review problem audiograms and shall determine whether there is a need for further evaluation. The employer shall provide to the person performing this evaluation the following information:

(a) A copy of the requirements for hearing conservation as set forth in paragraphs (c) through (n) of this section;

(b) The baseline audiogram and most recent audiogram of the employee to be evaluated;

(c) Measurements of background sound pressure levels in the audiometric test room as required in Appendix D: Audiometric Test Rooms.

(d) Records of audiometer calibrations required by paragraph (h)(5) of this section.

(8) Follow-up procedures.

(i) If a comparison of the annual audiogram to the baseline audiogram indicates a standard threshold shift as defined in paragraph (g)(10) of this section has occurred, the employee shall be informed of this fact in writing, within 21 days of the determination.

(ii) Unless a physician determines that the standard threshold shift is not work related or aggravated by occupational noise exposure, the employer shall ensure that the following steps are taken when a standard threshold shift occurs:

(a) Employees not using hearing protectors shall be fitted with hearing protectors, trained in their use and care, and required to use them.

(b) Employees already using hearing protectors shall be refitted and retained in the use of hearing protectors and provided with hearing protectors offering greater attenuation if necessary.

(c) The employee shall be referred for a clinical audiological evaluation or an otological examination, as appropriate, if additional testing is necessary or if the employer suspects that a medical pathology of the ear is caused or aggravated by the wearing of hearing protectors.

(d) The employee is informed of the need for an otological examination if a medical pathology of the ear that is unrelated to the use of hearing protectors is suspected.

(iii) If subsequent audiometric testing of an employee whose exposure to noise is less than an 8-hour TWA of 90 decibels indicates that a standard threshold shift is not persistent, the employer:

(a) Shall inform the employee of the new audiometric interpretation; and

(b) May discontinue the required use of hearing protectors for that employee.

(9) Revised baseline. An annual audiogram may be substituted for the baseline audiogram when, in the judgment of the audiologist, otolaryngologist or physician who is evaluating the audiogram:

(i) The standard threshold shift revealed by the audiogram is persistent; or

(ii) The hearing threshold shown in the annual audiogram indicates significant improvement over the baseline audiogram.

(10) Standard threshold shift.

(i) As used in this section, a standard threshold shift is a change in hearing threshold relative to the baseline audiogram of an average of 10 dB or more at 2000, 3000, and 4000 Hz in either ear.

(ii) In determining whether a standard threshold shift has occurred, allowance may be made for the contribution of aging (presbycusis) to the change in hearing level by correcting the annual audiogram according to the procedure described in Appendix F: *Calculation and Application of Age Correction to Audiograms.*

(h) Audiometric test requirements.

(1) Audiometric tests shall be pure tone, air conduction, hearing threshold examinations, with test frequencies including as a minimum 500, 1000, 2000, 3000, 4000, and 6000 Hz. Tests at each frequency shall be taken separately for each ear.

(2) Audiometric tests shall be conducted with audiometers (including microprocessor audiometers) that meet the specifications of, and are maintained and used in accordance with, American National Standard Specification for Audiometers, S3.6-1969.

(3) Pulsed-tone and self-recording audiometers, if used, shall meet the requirements specified in Appendix C: *Audiometric Measuring Instruments.*

(4) Audiometric examinations shall be administered in a room meeting the requirements listed in Appendix D: *Audiometric Test Rooms.*

(5) Audiometer calibration.

(i) The functional operation of the audiometer shall be checked before each day's use by testing a person with known, stable hearing thresholds, and by listening to the audiometer's output to make sure that the output is free from distorted or unwanted sounds. Deviations of 10 decibels or greater require an acoustic calibration.

(ii) Audiometer calibration shall be checked acoustically at least annually in accordance with Appendix E: *Acoustic Calibration of Audiometers.* Test frequencies below 500 Hz and above 6000 Hz may be omitted from this check. Deviations of 15 decibels or greater require an exhaustive calibration.

(iii) An exhaustive calibration shall be performed at least every two years in accordance with sections 4.1.2; 4.1.3.; 4.1.4.3; 4.2; 4.4.1; 4.4.2; 4.4.3; and 4.5 of the American National Standard Specification for Audiometers, S3.6-1969. Test frequencies below 500 Hz and above 6000 Hz may be omitted from this calibration.

(i) Hearing protectors.

(1) Employers shall make hearing protectors available to all employees exposed to an 8-hour time-weighted average of 85 decibels or greater at no cost to the employees. Hearing protectors shall be replaced as necessary.

(2) Employers shall ensure that hearing protectors are worn:

(i) By an employee who is required by paragraph (b)(1) of this section to wear personal protective equipment; and

(ii) By any employee who is exposed to an 8-hour time-weighted average of 85 decibels or greater, and who:

(a) Has not yet had a baseline audiogram established pursuant to paragraph (g)(5)(ii); or

(b) Has experienced a standard threshold shift.

(3) Employees shall be given the opportunity to select their hearing protectors from a variety of suitable hearing protectors provided by the employer.

(4) The employer shall provide training in the use and care of all hearing protectors provided to employees.

(5) The employer shall ensure proper initial fitting and supervise the correct use of all hearing protectors.

(j) Hearing protector attenuation.

(1) The employer shall evaluate hearing protector attenuation for the specific noise environments in which the protector will be used. The employer shall use one of the evaluation methods described in Appendix B: *Methods for Estimating the Adequacy of Hearing Protection Attenuation.*

(2) Hearing protectors must attenuate employee exposure at least to an 8-hour time-weighted average of 90 decibels as required by paragraph (b) of this section.

(3) For employees who have experienced a standard threshold shift, hearing protectors must attenuate employee exposure to an 8-hour time-weighted average of 85 decibels or below.

(4) The adequacy of hearing protector attenuation shall be re-evaluated whenever employee noise exposures increase to the extent that the hearing protectors provided may no longer provide adequate attenuation. The employee shall provide more effective hearing protectors where necessary.

(k) Training program.

(1) The employer shall institute a training program for all employees who are exposed to noise at or above an 8-hour time-weighted average of 85 decibels, and shall ensure employee participation in such program.

(2) The training program shall be repeated annually for each employee included in the hearing conservation program. Information provided in the training program shall be updated to be consistent with changes in protective equipment and work processes.

(3) The employer shall ensure that each employee is informed of the following:

(i) The effects of noise on hearing;

(ii) The purpose of hearing protectors, the advantages, disadvantages, and attenuation of various types, and instructions on selection, fitting, use, and care; and

(iii) The purpose of audiometric testing, and an explanation of the test procedures.

(l) Access to information and training materials.

(1) The employer shall make available to affected employees or their representatives copies of this standard and shall also post a copy in the workplace.

(2) The employer shall provide to affected employees any informational materials pertaining to the standard that are supplied to the employer by the Assistant Secretary.

(3) The employer shall provide, upon request, all materials related to the employer's training and education program pertaining to this standard to the Assistant Secretary and the Director.

(m) Recordkeeping.

(1) **Exposure measurements.** The employer shall maintain an accurate record of all employee exposure measurements required by paragraph (d) of this section.

(2) **Audiometric tests.**

(i) The employer shall retain all employee audiometric test records obtained pursuant to paragraph (g) of this section:

(ii) This record shall include:

(a) Name and job classification of the employee;

(b) Date of the audiogram;

(c) The examiner's name;

(d) Date of the last acoustic or exhaustive calibration of the audiometer; and

(e) Employee's most recent noise exposure assessment.

(f) The employer shall maintain accurate records of the measurements of the background sound pressure levels in audiometric test rooms.

(3) **Record retention.** The employer shall retain records required in this paragraph (m) for at least the following periods.

(i) Noise exposure measurement records shall be retained for two years.

(ii) Audiometric test records shall be retained for the duration of the affected employee's employment.

(4) **Access to records.** All records required by this section shall be provided upon request to employees, former employees, representatives designated by the individual employee, and the Assistant Secretary. The provisions of 29 CFR 1910.20(a)-(e) and (g)-(i) apply to access to records under this section.

(5) Transfer of records. If the employer ceases to do business, the employer shall transfer to the successor employer all records required to be maintained by this section, and the successor employer shall retain them for the remainder of the period prescribed in paragraph (m)(3) of this section.

(n) Appendices.

(1) Appendices A, B, C, D, and E to this section are incorporated as part of this section and the contents of these Appendices are mandatory.

(2) Appendices F and G to this section are informational and are not intended to create any additional obligations not otherwise imposed or to detract from any existing obligations.

(o) Exemptions. Paragraphs (c) through (n) of this section shall not apply to employers engaged in oil and gas well drilling and servicing operations.

(p) Startup date. Baseline audiograms required by paragraph (g) of this section shall be completed by March 1, 1984.

APPENDIX A: NOISE EXPOSURE COMPUTATION

This Appendix is Mandatory

I. Computation of Employee Noise Exposure

(1) Noise dose is computed using Table G-16a as follows:

(i) When the sound level, L, is constant over the entire work shift, the noise dose, D, in percent, is given by: D=100 C/T where C is the total length of the work day, in hours, and T is the reference duration corresponding to the measured sound level, L, as given in Table G-16a or by the formula shown as a footnote to that table.

(ii) When the workshift noise exposure is composed of two or more periods of noise at different levels, the total noise dose over the work day is given by:
$D=100\,(C_1/T_1+C_2/T_2+\ldots+C_n/T_n)$,
where C_n indicates the total time of exposure at a specific noise level, and T_n indicates the reference duration for that level as given by Table G-16a.

(2) The eight-hour time-weighted average sound level (TWA), in decibels, may be computed from the dose, in percent, by means of the formula: $TWA=16.61\log_{10}(D/100)+90$. For an eight-hour workshift with the noise level constant over the entire shift, the TWA is equal to the measured sound level.

(3) A table relating dose and TWA is given in Section II.

TABLE G-16A

A-weighted sound level, L (decibel)	Reference duration, T (hour)
80	32
81	27.9
82	24.3
83	21.1
84	16.4
85	16
86	13.9
87	12.1
88	10.6
89	9.2
90	8
91	7.0
92	6.1
93	5.3
94	4.6
95	4
96	3.5
97	3.0
98	2.6
99	2.3
100	2
101	1.7
102	1.5
103	1.3
104	1.1
105	1
106	0.87
107	0.76
108	0.66
109	0.57
110	0.5
111	0.44
112	0.38
113	0.33
114	0.29
115	0.25
116	*0.22*
117	*0.19*
118	*0.16*
119	*0.14*
120	*0.125*
121	*0.11*
122	*0.095*
123	*0.082*
124	*0.072*
125	*0.063*
126	*0.054*
127	*0.047*
128	*0.041*
129	*0.036*
130	*0.031*

In the above table the reference duration, T, is computed by

$$T=\frac{8}{2^{(L-90)/5}}$$

where L is the measured A-weighted sound level.

II. Conversion Between "Dose" and "8-Hour Time-Weighted Average" Sound Level

Compliance with paragraphs (c)-(r) of this regulation is determined by the amount of exposure to noise in the workplace. The amount of such exposure is usually measured with an audiodosimeter which gives a readout in terms of "dose." In order to better understand the requirements of the amendment, dosimeter readings can be converted to an "8-hour time-weighted average sound level." (TWA).

In order to convert the reading of a dosimeter into TWA, see Table A-1, below. This table applies to dosimeters that are set by the manufacturer to calculate dose or percent exposure according to the relationships in Table G-16a. So, for example, a dose of 91 percent over an eight hour day results in a TWA of 89.3 dB, and, a dose of 50 percent corresponds to a TWA of 85 dB.

If the dose as read on the dosimeter is less than or greater than the values found in Table A-1, the TWA may be calculated by using the formula: $TWA = 16.61 \log_{10} (D/100) + 90$ where TWA = 8-hour time-weighted average sound level and D = accumulated dose in percent exposure.

Table A-1.—Conversion From "Percent Noise Exposure" or "Dose" to "8-Hour Time-Weighted Average Sound Level" (TWA)

Dose or percent noise exposure	TWA
10	73.4
15	76.3
20	78.4
25	80.0
30	81.3
35	82.4
40	83.4
45	84.2
50	85.0
55	85.7
60	86.3
65	86.9
70	87.4
75	87.9
80	88.4
81	88.5
82	88.6
83	88.7
84	88.7
85	88.8
86	88.9
87	89.0
88	89.1
89	89.2
90	89.2
91	89.3
92	89.4
93	89.5
94	89.6
95	89.6
96	89.7
97	89.8
98	89.9
99	89.9
100	90.0
101	90.1
102	90.1
103	90.2
104	90.3
105	90.4
106	90.4
107	90.5
108	90.6
109	90.6

Table A-1.—Conversions From "Percent Noise Exposure" or "Dose" to "8-Hour Time-Weighted Average Sound level" (TWA)—Continued

Dose or percent noise exposure	TWA
110	90.7
111	90.8
112	90.8
113	90.9
114	90.9
115	91.1
116	91.1
117	91.1
118	91.2
119	91.3
120	91.3
125	91.6
130	91.9
135	92.2
140	92.4
145	92.7
150	92.9
155	93.2
160	93.4
165	93.6
170	93.8
175	94.0
180	94.2
185	94.4
190	94.6
195	94.8
200	95.0
210	95.4
220	95.7
230	96.0
240	96.3
250	96.6
260	96.9
270	97.2
280	97.4
290	97.7
300	97.9
310	98.2
320	98.4
330	98.6
340	98.8
350	99.0
360	99.2
370	99.4
380	99.6
390	99.8
400	100.0
410	100.2
420	100.4
430	100.5
440	100.7
450	100.8
460	101.0
470	101.2
480	101.3
490	101.5
500	101.6
510	101.8
520	101.9
530	102.0
540	102.2
550	102.3
560	102.4
570	102.6
580	102.7

Table A-1.—Conversions From "Percent Noise Exposure" or "Dose" to "8-Hour Time-Weighted Average Sound level" (TWA)—Continued

Dose or percent noise exposure	TWA
590	102.8
600	102.9
610	103.0
620	103.2
630	103.3
640	103.4
650	103.5
660	103.6
670	103.7
680	103.8
690	103.9
700	104.0
710	104.1
720	104.2
730	104.3
740	104.4
750	104.5
760	104.6
770	104.7
780	104.8
790	104.9
800	105.0
810	105.1
820	105.2
830	105.3
840	105.4
850	105.4
860	105.5
870	105.6
880	105.7
890	105.8
900	105.8
910	105.9
920	106.0
930	106.1
940	106.2
950	106.2
960	106.3
970	106.4
980	106.5
990	106.5
999	106.6

APPENDIX B: METHODS FOR ESTIMATING THE ADEQUACY OF HEARING PROTECTOR ATTENUATION

This Appendix is Mandatory

For employees who have experienced a significant threshold shift, hearing protector attenuation must be sufficient to reduce employee exposure to a TWA of 85 dB. Employers must select one of the following methods by which to estimate the adequacy of hearing protector attenuation.

The most convenient method is the Noise Reduction Rating (NRR) developed by the Environmental Protection Agency (EPA). According to EPA regulation, the NRR must be shown on the hearing protector package. The NRR is then related to an individual worker's noise environment in order to assess the adequacy of the attenuation of a given hearing protector. This Appendix describes four methods of using the NRR to determine whether a particular hearing protector provides adequate protection within a given exposure environment. Selection among the four procedures is dependent upon the employer's noise measuring instruments.

Instead of using the NRR, employers may evaluate the adequacy of hearing protector attenuation by using one of the three methods developed by the National Institute for Occupational Safety and Health (NIOSH), which are described in the "List of Personal Hearing Protectors and Attenuation Data," HEW Publication No. 76-120, 1975, pages 21-37. These methods are known as NIOSH methods #1, #2 and #3. The NRR described below is a simplification of NIOSH method #2. The most complex method is NIOSH method #1, which is probably the most accurate method since it uses the largest amount of spectral information from the individual employee's noise environment. As in the case of the NRR method described below, if one of the NIOSH methods is used, the selected method must be applied to an individual's noise environment to assess the adequacy of the attenuation. Employers should be careful to take a sufficient number of measurements in order to achieve a representative sample for each time segment.

Note.—The employer must remember that calculated attenuation values reflect realistic values only to the extent that the protectors are properly fitted and worn.

When using the NRR to assess hearing protector adequacy, one of the following methods must be used:

(i) When using a dosimeter that is capable of C-weighted measurements:

(A) Obtain the employee's C-weighted dose for the entire workshift, and convert to TWA (see Appendix A, II).

(B) Subtract the NRR from the C-weighted TWA to obtain the estimated A-weighted TWA under the ear protector.

(ii) When using a dosimeter that is not capable of C-weighted measurements, the following method may be used:

(A) Convert the A-weighted dose to TWA (see Appendix A).

(B) Subtract 7 dB from the NRR.

(C) Subtract the remainder from the A-weighted TWA to obtain the estimated A-weighted TWA under the ear protector.

(iii) When using a sound level meter set to the A-weighting network:

(A) Obtain the employee's A-weighted TWA.

(B) Subtract 7 dB from the NRR, and subtract the remainder from the A-weighted TWA to obtain the estimated A-weighted TWA under the ear protector.

(iv) When using a sound level meter set on the C-weighting network:

(A) Obtain a representative sample of the C-weighted sound levels in the employee's environment.

(B) Subtract the NRR from the C-weighted average sound level to obtain the estimated A-weighted TWA under the ear protector.

(v) When using area monitoring procedures and a sound level meter set to the A-weighing network.

(A) Obtain a representative sound level for the area in question.

(B) Subtract 7 dB from the NRR and subtract the remainder from the A-weighted sound level for that area.

(vi) When using area monitoring procedures and a sound level meter set to the C-weighting network:

(A) Obtain a representative sound level for the area in question.

(B) Subtract the NRR from the C-weighted sound level for that area.

APPENDIX C: AUDIOMETRIC MEASURING INSTRUMENTS

This Appendix is Mandatory

1. In the event that pulsed-tone audiometers are used, they shall have a tone on-time of at least 200 milliseconds.

2. Self-recording audiometers shall comply with the following requirements:

(A) The chart upon which the audiogram is traced shall have lines at positions corresponding to all multiples of 10 dB hearing level within the intensity range spanned by the audiometer. The lines shall be equally spaced and shall be separated by at least ¼ inch. Additional increments are optional. The audiogram pen tracings shall not exceed 2 dB in width.

(B) It shall be possible to set the stylus manually at the 10-dB increment lines for calibration purposes.

(C) The slewing rate for the audiometer attenuator shall not be more than 6 dB/sec except that an initial slewing rate greater than 6 dB/sec is permitted at the beginning of each new test frequency, but only until the second subject response.

(D) The audiometer shall remain at each required test frequency for 30 seconds (±3 seconds). The audiogram shall be clearly marked at each change of frequency and the actual frequency change of the audiometer shall not deviate from the frequency boundaries marked on the audiogram by more than ±3 seconds.

(E) It must be possible at each test frequency to place a horizontal line segment parallel to the time axis on the audiogram, such that the audiometric tracing crosses the line segment at least six times at that test frequency. At each test frequency the threshold shall be the average of the midpoints of the tracing excursions.

APPENDIX D: AUDIOMETRIC TEST ROOMS

This Appendix is Mandatory

Rooms used for audiometric testing shall not have background sound pressure levels exceeding those in Table D-1 when measured by equipment conforming at least to the Type 2 requirements of American National Standard Specification for Sound Level Meters, S1.4-1971 (R1976), and to the Class II requirements of American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1971 (R1976).

Table D-1.—Maximum Allowable Octave-Band Sound Pressure Levels for Audiometric Test Rooms

Octave-band center frequency (Hz)	500	1000	2000	4000	8000
Sound pressure level (dB)	40	40	47	57	62

APPENDIX E: ACOUSTIC CALIBRATION OF AUDIOMETERS

This Appendix is Mandatory

Audiometer calibration shall be checked acoustically, at least annually, according to the procedures described in this Appendix. The equipment necessary to perform these measurments is a sound level meter, octave-band filter set, and a National Bureau of Standards 9A coupler. In making these measurements, the accuracy of the calibrating equipment shall be sufficient to determine that the audiometer is within the tolerances permitted by American Standard Specification for Audiometers, S3.6-1969.

(1) Sound Pressure Output Check

A. Place the earphone coupler over the microphone of the sound level meter and place the earphone on the coupler.

B. Set the audiometer's hearing threshold level (HTL) dial to 70 dB.

C. Measure the sound pressure level of the tones that each test frequency from 500 Hz through 6000 Hz for each earphone.

D. At each frequency the readout on the sound level meter should correspond to the levels in Table E-1 or Table E-2, as appropriate, for the type of earphone, in the column entitled "sound level meter reading."

(2) Linearity Check

A. With the earphone in place, set the frequency to 1000 Hz and the HTL dial on the audiometer to 70 dB.

B. Measure the sound levels in the coupler at each 10-dB decrement from 70 dB to 10 dB, noting the sound level meter reading at each setting.

C. For each 10-dB decrement on the audiometer the sound level meter should indicate a corresponding 10 dB decrease.

D. This measurement may be made electrically with a voltmeter connected to the earphone terminals.

(3) Tolerances

When any of the measured sound levels deviate from the levels in Table E-1 or Table E-2 by ±3 dB at any test frequency between 500 and 3000 Hz, 4 dB at 4000 Hz, or 5 dB at 6000 Hz, an exhaustive calibration is advised. An exhaustive calibration is required if the deviations are greater than 10 dB at any test frequency.

Table E-1.—Reference Threshold Levels for Telephonics—TDH-39 Earphones

Frequency, Hz	Reference threshold level for TDH-39 earphones, dB	Sound level meter reading, dB
500	11.5	81.5
1000	7	77
2000	9	79
3000	10	80
4000	9.5	79.5
6000	15.5	85.5

Table E-2.—Reference Threshold Levels for Telephonics—TDH-49 Earphones

Frequency, Hz	Reference threshold level for TDH-49 earphones, dB	Sound level meter reading, dB
500	13.5	83.5
1000	7.5	77.5
2000	11	81.0
3000	9.5	79.5
4000	10.5	80.5
6000	13.5	83.5

APPENDIX F: CALCULATIONS AND APPLICATION OF AGE CORRECTIONS TO AUDIOGRAMS

This Appendix is Non-Mandatory

In determining whether a standard threshold shift has occurred, allowance may be made for the contribution of aging to the change in hearing level by adjusting the most recent audiogram. If the employer chooses to adjust the audiogram, the employer shall follow the procedure described below. This procedure and the age correction tables were developed by the National Institute for Occupational Safety and Health in the criteria document entitled "Criteria for a Recommended Standard ... Occpational Exposure to Noise," ((HSM)-11001).

For each audiometric test frequency;

(I) Determine from Tables F-1 or F-2 the age correction values for the employee by:

(A) Finding the age at which the most recent audiogram was taken and recording the corresponding values of age corrections at 1000 Hz through 6000 Hz;

(B) Finding the age at which the baseline audiogram was taken and recording the corresponding values of age corrections at 1000 Hz through 6000 Hz.

(II) Subtract the values found in step (i)(A) from the value found in step (i)(B).

(III) The differences calculated in step (ii) represented that portion of the change in hearing that may be due to aging.

Example: Employee is a 32-year-old male. The audiometric history for his right ear is shown in decibels below.

	Audiometric test frequency (Hz)				
Employee's age	1000	2000	3000	4000	6000
26	10	5	5	10	5
*27	0	0	0	5	5
28	0	0	0	10	5
29	5	0	5	15	5
30	0	5	10	20	10
31	5	10	20	15	15
*32	5	10	10	25	20

The audiogram at age 27 is considered the baseline since it shows the best hearing threshold levels. Asterisks have been used to identify the baseline and most recent audiogram. A threshold shift of 20 dB exists at 4000 Hz between the audiograms taken at ages 27 and 32.

(The threshold shift is computed by subtracting the hearing threshold at age 27, which was 5, from the hearing threshold at age 32, which is 25). A retest audiogram has confirmed this shift. The contribution of aging to this change in hearing may be estimated in the following manner:

Go to Table F-1 and find the age correction values (in dB) for 4000 Hz at age 27 and age 32.

	Frequency (Hz)				
	1000	2000	3000	4000	6000
Age 32	6	5	7	10	14
Age 27	5	4	6	7	11
Difference	1	1	1	3	3

The difference represents the amount of hearing loss that may be attributed to aging in the time period between the baseline audiogram and the most recent audiogram. In this example, the difference at 4000 Hz is 3 dB. This value is subtracted from the hearing level at 4000 Hz, which in the most recent audiogram is 25, yielding 22 after adjustment. Then the hearing threshold in the baseline audiogram at 4000 Hz (5) is subtracted from the adjusted annual audiogram hearing threshold at 4000 Hz (22). Thus the age-corrected threshold shift would be 17 dB (as opposed to a threshold shift of 20 dB without age correction).

Table F-1.—Age Correction Values In Decibels For Males

Years	Audiometric Test Frequencies (Hz)				
	1000	2000	3000	4000	6000
20 or younger	5	3	4	5	8
21	5	3	4	5	8
22	5	3	4	5	8
23	5	3	4	6	9
24	5	3	5	6	9
25	5	3	5	7	10
26	5	4	5	7	10
27	5	4	6	7	11
28	6	4	6	8	11
29	6	4	6	8	12
30	6	4	6	9	12
31	6	4	7	9	13
32	6	5	7	10	14
33	6	5	7	10	14
34	6	5	8	11	15
35	7	5	8	11	15
36	7	5	9	12	16
37	7	6	9	12	17
38	7	6	9	13	17
39	7	6	10	14	18
40	7	6	10	14	19
41	7	6	10	14	20
42	8	7	11	16	20
43	8	7	12	16	21
44	8	7	12	17	22
45	8	7	13	18	23
46	8	8	13	19	24
47	8	8	14	19	24
48	9	8	14	20	25
49	9	9	15	21	26
50	9	9	16	22	27
51	9	9	16	23	28
52	9	10	17	24	29
53	9	10	18	25	30
54	10	10	18	26	31

Table F-1.—Age Correction Values In Decibels For Males—Continued

Years	Audiometric Test Frequencies (Hz)				
	1000	2000	3000	4000	6000
55	10	11	19	27	32
56	10	11	20	28	34
57	10	11	21	29	35
58	10	12	22	31	36
59	11	12	22	32	37
60 or older	11	13	23	33	38

Table F-2.—Age Correction Values In Decibels For Females

Years	Audiometric Test Frequencies (Hz)				
	1000	2000	3000	4000	6000
20 or younger	7	4	3	3	6
21	7	4	4	3	6
22	7	4	4	4	6
23	7	5	4	4	7
24	7	5	4	4	7
25	8	5	4	4	7
26	8	5	5	4	8
27	8	5	5	5	8

Table F-2.—Age Correction Values In Decibels For Females —Continued

Years	Audiometric Test Frequencies (Hz)				
	1000	2000	3000	4000	6000
28	8	5	5	5	8
29	8	5	5	5	9
30	8	6	5	5	9
31	8	6	6	5	9
32	9	6	6	6	10
33	9	6	6	6	10
34	9	6	6	6	10
35	9	6	7	7	11
36	9	7	7	7	11
37	9	7	7	7	12
38	10	7	7	7	12
39	10	7	8	8	12
40	10	7	8	8	13
41	10	8	8	8	13
42	10	8	9	9	13
43	11	8	9	9	14
44	11	8	9	9	14
45	11	8	10	10	15
46	11	9	10	10	15
47	11	9	10	11	16
48	12	9	11	11	16
49	12	9	11	11	16
50	12	10	11	12	17
51	12	10	12	12	17
52	12	10	12	13	18
53	13	10	13	13	18
54	13	11	13	14	19
55	13	11	14	14	19
56	13	11	14	15	20
57	13	11	15	15	20
58	14	12	15	16	21
59	14	12	16	16	21
60 or older	14	12	16	17	22

APPENDIX G: MONITORING NOISE LEVELS NON-MANDATORY INFORMATIONAL APPENDIX

This appendix provides information to help employers comply with the noise monitoring obligations that are part of the hearing conservation amendment.

What is the purpose of noise monitoring?

This revised amendment requires that employees be placed in a hearing conservation program if they are exposed to average noise levels of 85 dB or greater during an 8 hour workday. In order to determine if exposures are at or above this level, it may be necessary to measure or monitor the actual noise levels in the workplace and to estimate the noise exposure or "dose" received by employees during the workday.

When is it necessary to implement a noise monitoring program?

It is not necessary for every employer to measure workplace noise. Noise monitoring or measuring must be conducted only when exposures are at or above 85 dB. Factors which suggest that noise exposures in the workplace may be at this level include employee complaints about the loudness of noise, indications that employees are losing their hearing,

or noisy conditions which make normal conversation difficult. The employer should also consider any information available regarding noise emitted from specific machines. In addition, actual workplace noise measurements can suggest whether or not a monitoring program should be initiated.

How is noise measured?

Basically, there are two different instruments to measure noise exposures: the sound level meter and the dosimeter. A sound level meter is a device that measures the intensity of sound at a given moment. Since sound level meters provide a measure of sound intensity at only one point in time, it is generally necessary to take a number of measurements at different times during the day to estimate noise exposure over a workday. If noise levels fluctuate, the amount of time noise remains at each of the various measured levels must be determined.

To estimate employee noise exposures with a sound level meter it is also generally necessary to take several measurements at different locations within the workplace. After appropriate sound level meter readings are obtained, people sometimes draw "maps" of the sound levels within different areas of the workplace. By using a sound level "map" and information on employee locations throughout the day, estimates of individual exposure levels can be developed. This measurement method is generally referred to as *area* noise monitoring.

A dosimeter is like a sound level meter except that it stores sound level measurements and integrates these measurements over time, providing an average noise exposure reading for a given period of time, such as an 8-hour workday. With a dosimeter, a microphone is attached to the employee's clothing and the exposure measurement is simply read at the end of the desired time period. A reader may be used to read-out the dosimeter's measurements. Since the dosimeter is worn by the employee, it measures noise levels in those locations in which the employee travels. A sound level meter can also be positioned within the immediate vicinity of the exposed worker to obtain an individual exposure estimate. Such procedures are generally referred to as *personal* noise monitoring.

Area monitoring can be used to estimate noise exposure when the noise levels are relatively constant and employees are not mobile. In workplaces where employees move about in different areas or where the noise intensity tends to fluctuate over time, noise exposure is generally more accurately estimated by the personal monitoring approach.

In situations where personal monitoring is appropriate, proper positioning of the microphone is necessary to obtain accurate measurements. With a dosimeter, the microphone is generally located on the shoulder and remains in that position for the entire workday. With a sound level meter, the microphone is stationed near the employee's head, and the instrument is usually held by an individual who follows the employee as he or she moves about.

Manufacturer's instructions, contained in dosimeter and sound level meter operating manuals, should be followed for calibration and maintenance. To ensure accurate results, it is considered good professional practice to calibrate instruments before and after each use.

How often is it necessary to monitor noise levels?

The amendment requires that when there are significant changes in machinery or production processes that may result in increased noise levels, remonitoring must be conducted to determine whether additional employees need to be included in the hearing conservation program. Many companies choose to remonitor periodically (once every year or two) to ensure that all exposed employees are included in their hearing conservation programs.

Where can equipment and technical advice be obtained?

Noise monitoring equipment may be either purchased or rented. Sound level meters cost about $500 to $1,000, while dosimeters range in price from about $750 to $1,500. Smaller companies may find it more economical to rent equipment rather than to purchase it. Names of equipment suppliers may be found in the telephone book (Yellow Pages) under headings such as: "Safety Equipment," "Industrial Hygiene," or "Engineers-Acoustical." In addition to providing information on obtaining noise monitoring equipment, many companies and individuals included under such listings can provide professional advice on how to conduct a valid noise monitoring program. Some audiological testing firms and industrial hygiene firms also provide noise monitoring services. Universities with audiology, industrial hygiene, or acoustical engineering departments may also provide information or may be able to help employers meet their obligations under this amendment.

Free, on-site assistance may be obtained from OSHA-supported state and private consultation organizations. These safety and health consultative entities generally give priority to the needs of small businesses. See the attached directory for a listing of organizations to contact for aid.

OSHA ONSITE CONSULTATION PROJECT DIRECTORY

State	Office and address	Contact
Alabama	Alabama Consultation Program, P.O. Box 6005, University, Alabama 35486	(205) 348-7136, Mr. William Weems, Director.
Alaska	State of Alaska, Department of Labor, Occupational Safety & Health, 3301 Eagle St., Pouch 7-022, Anchorage, Alaska 99510.	(907) 276-5013, Mr. Stan Godlove, Project Manager (All Mail).
American Samoa	Service not yet available.	
Arizona	Consultation and Training, Arizona Division of Occupational Safety and Health, P.O. Box 19070, 1624 W. Adams, Phoenix, Ariz. 85005.	(602) 255-5795, Mr. Thomas Ramsey, Manager.
Arkansas	OSHA Consultation, Arkansas Department of Labor, 1022 High St., Little Rock, Ark. 72202	(501) 371-2992, Mr. George Smith, Project Director.
California	CALOSHA Consultation Service, 2nd Floor, 525 Golden Gate Avenue, San Francisco, Calif. 94102.	(415) 557-2870, Mr. Emmett Jones, Chief.
Colorado	Occupational Safety & Health Section, Colorado State University, Institute of Rural Environmental Health, 119 Veterinary Science Building, Fort Collins, Colo. 80523.	(303) 491-6154, Dr. Ray M. Bechen, Project Director.
Connecticut	Division of Occupational Safety & Health, Connecticut Department of Labor, 200 Folly Brook Boulevard, Wethersfield, Conn. 06109.	(203) 566-4550, Mr. Leo Alix, Director.
Delaware	Delaware Department of Labor, Division of Industrial Affairs, 820 North French Street, 6th Floor, Wilmington, Del. 19801.	(302) 571-3908, Mr. Bruno Stalvadori, Director.
District of Columbia	Occupational Safety & Health Division, District of Columbia, Department Employment Services, Office of Labor Standards, 2800 Newton Street NE., Washington, D.C. 20018.	(202) 832-1230, Mr. Lorenzo M. White, Acting Associate Director.
Florida	Department of Labor & Employment Security, Bureau of Industrial Safety and Health, LaFayette Building, Room 204, 2551 Executive Center Circle West, Tallahassee, Fla. 32301.	(904) 488-3044, Mr. John C. Glenn, Administrator.
Georgia	Economic Development Division, Technology and Development Laboratory, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Ga. 30332.	(404) 894-3806, Mr. William C. Howard, Assistant to Director, Mr. James Burson, Project Manager.

OSHA ONSITE CONSULTATION PROJECT DIRECTORY—Continued

State	Office and address	Contact
Guam	Department of Labor, Government of Guam, 23548 Guam Main Facility, Agana, Guam 96921	(671) 772-8291, Joe R. San Agustin, Director.
Hawaii	Education and Information Branch, Division of Occupational Safety and Health, Suite 910, 677 Ala Moana, Honolulu, Hawaii 96813.	(808) 548-2511, Mr. Don Alper, Manager (Air Mail).
Idaho	OSHA Onsite Consultation Program, Boise State University, Community and Environmental Health, 1910 University Drive, Boise, Idaho 83725.	(208) 385-3929, Dr. Eldon Edmundson, Director.
Illinois	Division of Industrial Services, Dept. of Commerce and Community Affairs, 310 S. Michigan Avenue, 10 Floor, Chicago, Ill. 60601.	(800) 972-4140/4216 (Toll-free in State), (312) 793-3270, Mr. Stan Czwineki, Assistant Director.
Iowa	Bureau of Labor, 307 E. Seventh Street, Des Moines, Iowa 50319	(515) 281-3606, Mr. Allen J. Meier, Commissioner.
Indiana	Bureau of Safety, Education and Training, Indiana Division of Labor, 1013 State Office Building, Indianapolis, Indiana 46204.	(317) 633-5845, Mr. Harold Mills, Director.
Kansas	Kansas Dept. of Human Resources, 401 Topeka Ave., Topeka, Kans. 66603	(913) 296-4066, Ms. Jerry Abbott, Secretary.
Kentucky	Education and Training, Occupational Safety and Health, Kentucky Department of Labor, 127 Building, 127 South, Frankfort, Ky. 40601.	(502) 564-6895, Mr. Larry Potter, Director.
Louisiana	No services available as yet (Pending FY 83).	
Maine	Division of Industrial Safety, Maine Dept. of Labor, Labor Station 45, State Office Building, Augusta, Maine 04333.	(207) 289-3331, Mr. Lester Wood, Director.
Maryland	Consultation Services, Division of Labor & Industry, 501 St. Paul Place, Baltimore, Maryland 21202	(301) 659-4210, Ms. Ileana O'Brien, Project Manager, 7(c)(1) Agreement.
Massachusetts	Division of Industrial Safety, Massachusetts Department of Labor and Industries, 100 Cambridge Street, Boston, Massachusetts 02202.	(617) 727-3567, Mr. Edward Noseworthy, Project Director
Michigan (Health)	Special Programs Section, Division of Occupational Health, Michigan Dept. of Public Health, 3500 N. Logan, Lansing, Mich. 48909.	(517) 373-1410, Mr. Irving Davis, Chief.
Michigan (Safety)	Safety Education & Training Division Bureau of Safety and Regulation, Michigan Department of Labor, 7150 Harris Drive, Box 30015, Lansing, Michigan 48909.	(517) 322-1809, Mr. Alan Harvie, Chief.
Minnesota	Training and Education Unit, Department of Labor and Industry, 5th Floor, 444 Lafayette Road, St. Paul, Minn. 55101.	(612) 296-2973, Mr. Timothy Tierney, Project Manager
Mississippi	Division of Occupational Safety and Health, Mississippi State Board of Health, P.O. Box 1700, Jackson, Mississippi 39205.	(601) 982-6315, Mr. Henry L. Laird, Director.
Missouri	Missouri Department of Labor and Industrial Relations, 722 Jefferson Street, Jefferson City, Missouri 65101	1-(800) 392-0208, (314) 751-3403, Ms. Paula Smith, Mr. ...m Brake.
Montana	Montana Bureau of Safety & Health, Division of Workers Compensation, 815 Front Street, Helena, Montana 59601.	(406) 449-3402, Mr. Ed Gatzemeier, Chief.
Nebraska	Nebraska Department of Labor, State House Station, State Capitol, P.O. Box 94600, Lincoln, Nebraska 68509.	475-8451 Ext. 258, Mr. Joseph Carroll, Commissioner
Nevada	Department of Occupational Safety and Health, Nevada Industrial Commission, 515 E. Musser Street, Carson City, Nev. 89714.	(702) 885-5240, Mr. Allen Traenkner, Director.
New Hampshire	For information contact	Office of Consultation Programs, Room N3472 200 Constitution Avenue, N.W. Washington, D.C. 20210, Phone: (202) 523-8985.
New Jersey	New Jersey Department of Labor and Industry Division of Work Place Standards, CN-054, Trenton, New Jersey 08625.	(609) 292-2313, FTS-8-477-2313, Mr. William Clark, Assistant Commissioner.
New Mexico	OSHA Consultation, Health and Environment Department, Environmental Improvement Division, Occupational Health & Safety Section, 4215 Montgomery Boulevard, NE., Albuquerque, New Mexico 87109.	(505) 842-3387, Mr. Albert M. Stevens, Project Manager.
New York	Division of Safety and Health, New York State Department of Labor, 2 World Trade Center, Room 6995, New York, New York 10047.	(212) 488-7746/7, Mr. Joseph Alleva, Project Manager, DOSH.
North Carolina	Consultation Services, North Carolina Department of Labor, 4 West Edenton Street, Raleigh, N.C. 27601.	(919) 733-4885, Mr. David Pierce, Director.
North Dakota	Division of Environmental Research, Department of Health, Missouri Office Building, 1200 Missouri Avenue, Bismarck, N. Dak. 58505.	(701) 224-2348, Mr. Jay Crawford, Director.
Ohio	Department of Industrial Relations, Division of Onsite Consultation, P.O. Box 825, 2323 5th Avenue, Columbus, Ohio 43216.	(800) 282-1425 (Toll-free in State), (614) 466-7485, Mr. Andrew Doehrel, Project Manager.
Oklahoma	OSHA Division, Oklahoma Department of Labor, State Capitol, Suite 118, Oklahoma City, Okla. 73105.	(405) 521-2461, Mr. Charles W. McGlon, Director.
Oregon	Consultative Section, Department of Workers' Compensation, Accident Prevention Division, Room 102, Building 1, 2110 Front Street NE., Salem, Oregon 97310.	(503) 378-2690, Mr. Jack Buckland, Supervisor.
Pennsylvania	For information contact	Office of Consultation Programs, Room N3472, 200 Constitution Avenue NW., Washington, D.C. 20210, Phone: (202) 523-8985.
Puerto Rico	Occupational Safety & Health, Puerto Rico Department of Labor and Human Resources, 505 Munoz Rivera Ave., 21st Floor, Hato Rey, Puerto Rico 00919.	(809) 754-2134, Mr. John Cinque, Assistant Secretary, (Air Mail).
Rhode Island	Division of Occupational Health, Rhode Island Department of Health, The Cannon Building, 206 Health Department Building, Providence, R.I. 02903.	(401) 277-2438, Mr. James E. Hickey, Chief.
South Carolina	Consultation and Monitoring, South Carolina Department of Labor, P.O. Box 11329, Columbia, S.C. 29211.	(803) 758-8921, Mr. Robert Peck, Director, 7(c)(1), Project.
South Dakota	South Dakota Consultation Program, South Dakota State University, S.T.A.T.E.-Engineering Extension, 201 Pugsley Center-SDSO, Brookings, S. Dak. 57007.	(605) 688-4101, Mr. James Ceglian, Director.
Tennessee	OSHA Consultative Services, Tennessee Department of Labor, 2nd Floor, 501 Union Building, Nashville, Tennessee 37219.	(615) 741-2793, Mr. L. H. Craig Director.
Texas	Division of Occupational Safety and State Safety Engineer, Texas Department of Health and Resources, 1100 West 49th Street, Austin, Texas 78756.	(512) 458-7287, Mr. Walter G. Martin, P.E. Director.
Trust Territories	Service not yet available.	
Utah	Utah Job Safety and Health Consultation Service, Suite 4004, Crane Building, 307 West 200 South, Salt Lake City, Utah 84101.	(801) 533-7927/8/9, Mr. H. M. Bergeson, Project Director.
Vermont	Division of Occupational Safety and Health, Vermont Department of Labor and Industry, 118 State Street, Montpelier, Vt. 05602.	(802) 828-2765, Mr. Robert Moleod, Project Director.
Virginia	Department of Labor and Industry, P.O. Box 12064, 205 N. 4th Street, Richmond, Va. 23241	(804) 786-6575, Mr. Robert Beard, Commissioner.
Virgin Islands	Division of Occupational Safety and Health, Virgin Islands Department of Labor, Lagoon Street, Room 207, Frederiksted, Virgin Islands 00840.	(809) 772-1315, Mr. Louis Llanos, Deputy Director-DOSH.
Washington	Department of Labor and Industry, P.O. Box 207, Olympia, Wash. 98504	(206) 753-6300, Mr. James Sullivan, Assistant Director.
West Virginia	West Virginia Department of Labor, Room 451B, State Capitol, 1800 Washington Street, Charleston, W. Va. 25306.	FTS 8-558-7890, Mr. Lawrence Barker, Commissioner.
Wisconsin (Health)	Section of Occupational Health, Department of Health and Social Services, P.O. Box 309, Madison, Wisconsin 53701.	(608) 266-0417, Ms. Patricia Natzke, Acting Chief.
Wisconsin (Safety)	Division of Safety and Buildings, Department of Industry, Labor and Human Relations, 1570 E. Moreland Blvd., Waukesha, Wis. 53186.	(414) 544-2688, Mr. Richard Michalski, Supervisor.
Wyoming	Wyoming Occupational Health and Safety Department, 200 East 8th Avenue, Cheyenne, Wyo. 82002.	(307) 777-7786, Mr. Donald Owsley, Health and Safety Administrator.

APPENDIX H: AVAILABILITY OF REFERENCED DOCUMENTS

Paragraphs (c) through (o) of 29 CFR 1910.95 and the accompanying appendices contain provisions which incorporate publications by reference. Generally, the publications provide criteria for instruments to be used in monitoring and audiometric testing. These criteria are intended to be mandatory when so indicated in the applicable paragraphs of Section 1910.95 and appendices.

It should be noted that OSHA does not require that employers purchase a copy of the referenced publications. Employers, however, may desire to obtain a copy of the referenced publications for their own information.

The designation of the paragraph of the standard in which the referenced publications appear, the titles of the publications, and the availability of the publication are as follows:

Paragraph designation	Referenced publication	Available from—
Appendix B	"List of Personal Hearing Protectors and Attenuation Data," HEW Pub. No. 76-120, 1975, NTIS-PB267461.	National Technical Information Service, Port Royal Road, Springfield, VA 22161.
Appendix D	"Specification for Sound Level Meters," S1.4-1971 (R1976).	American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.
§1910.95(k)(2), appendix E	"Specifications for Audiometers," S3.6-1969.	American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.
Appendix D	"Specification for Octave, Half-Octave and Third-Octave Band Filter Sets," S1.11-1971 (R1976).	Back Numbers Department, Dept. STD, American Institute of Physics, 333 E. 45 St., New York, NY 10017; American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

The referenced publications (or a microfiche of the publications) are available for review at many universities and public libraries throughout the country. These publications may also be examined at the OSHA Technical Data Center, Room N2439, United States Department of Labor, 200 Constitution Avenue, NW., Washington, D.C. 20210, (202) 523-9700 or at any OSHA Regional Office (see telephone directories under United States Government—Labor Department).

APPENDIX I: DEFINITIONS

These definitions apply to the following terms as used in paragraphs (c) through (n) of 29 CFR 1910.95.

Action level—An 8-hour time-weighted average of 85 decibels measured on the A-scale, slow response, or equivalently, a dose of fifty percent.

Audiogram—A chart, graph, or table resulting from an audiometric test showing an individual's hearing threshold levels as a function of frequency.

Audiologist—A professional, specializing in the study and rehabilitation of hearing, who is certified by the American Speech-Language-Hearing Association or licensed by a state board of examiners.

Baseline audiogram—The audiogram against which future audiograms are compared.

Criterion sound level—A sound level of 90 decibels.

Decibel (dB)—Unit of measurement of sound level.

Hertz (Hz)—Unit of measurement of frequency, numerically equal to cycles per second.

Medical pathology—A disorder or disease. For purposes of this regulation, a condition or disease affecting the ear, which should be treated by a physician specialist.

Noise dose—The ratio, expressed as a percentage, of (1) the time integral, over a stated time or event, of the 0.6 power of the measured SLOW exponential time-averaged, squared A-weighted sound pressure and (2) the product of the criterion duration (8 hours) and the 0.6 power of the squared sound pressure corresponding to the criterion sound level (90 dB).

Noise dosimeter—An instrument that integrates a function of sound pressure over a period of time in such a manner that it directly indicates a noise dose.

Otolaryngologist—A physician specializing in diagnosis and treatment of disorders of the ear, nose and throat.

Representative exposure—Measurements of an employee's noise dose or 8-hour time-weighted average sound level that the employers deem to be representative of the exposures of other employees in the workplace.

Sound level—Ten times the common logarithm of the ratio of the square of the measured A-weighted sound pressure to the square of the standard reference pressure of 20 micropascals. Unit: decibels (dB). For use with this regulation, SLOW time response, in accordance with ANSI S1.4-1971 (R1976), is required.

South level meter—An instrument for the measurement of sound level.

Time-weighted average sound level—That sound level, which if constant over an 8-hour exposure, would result in the same noise dose as is measured.

Chapter 10

Ionizing Radiation

by C. Lyle Cheever, MS, MBA

This chapter presents the basic concepts of ionizing radiation and safe handling of radioactive materials to provide the framework within which the safety of ionizing radiation conditions can be evaluated. The chapter is directed to health and safety professionals who need a basic understanding of radiation safety. Health and safety professionals should also know where to find consultation and technical help on specific radiation problems. The control of ionizing radiation exposures requires special training in health physics, and professionals qualified in health physics should be obtained for this work. Radiation safety should be part of an organization's total health and safety program. The introduction of radiation devices or radioactive materials entails radiation safety reviews, engineering studies, and facility modifications. It may be necessary to alter traffic patterns of personnel and mobile equipment to minimize the spread of radioactive materials in the event of an accident.

The health and safety professional should have general knowledge of the nature of radiation, the detection of radiation, permissible exposure limits (PELs), biological effects of radiation, monitoring techniques, procedures, and control measures. Facility personnel need to be properly advised of radiation hazards and safe procedures. The health and safety professional should ensure that health physicists review or oversee radiation installations to ensure compliance with federal, state, and local regulations and company policies. Medical and emergency plans must be in place.

Effective accident prevention techniques are required for the control of radiation exposures to personnel. Radiation hazards can in some cases be controlled with common safety measures. In other cases, health physicists must provide expert guidance. Some radiation control operations entail extraordinarily expensive facilities and equipment. The organization and the health and safety professional must see that the proper actions are taken.

Basic information on the characteristics of radiation, standards for exposure limitation, safety factors, and control measures

are presented here. As an aid to further study, consult the Bibliography at the end of this chapter. Also, visit the websites of the Health Physics Society (www.health-physics.com) and the National Safety Council (www.nsc.org) to access a wealth of information on ionizing radiation protection.

IONIZING RADIATION TERMS

In order to discuss intelligently the health and safety aspects of ionizing radiation, an understanding of some basic terminology is necessary. Brief definitions of some important terms are given. In the text, English units of radiation exposure are listed first, followed by the SI (metric) units in parentheses. Figure 10–1 illustrates the process of radioactive disintegration.

Activity The number of nuclear disintegrations occurring in a given quantity of material per unit of time.

Alpha-particle (alpha-radiation, α) An alpha-particle is made up of two neutrons and two protons that give it a unit charge of +2. It is emitted from the nucleus of a radioactive atom and causes high-density ionization. Alpha-particles transfer their energy in a very short distance and are readily stopped by a piece of paper or the top, dead layer of the skin. Alpha-radioactivity is therefore primarily an internal radiation hazard.

Annihilation The process by which a negative electron and a positive electron, or positron, combine and disappear. The process results in the emission of electromagnetic radiation.

Annual limit on intake (ALI) The activity of a radionuclide that, taken into the body over the course of one year,

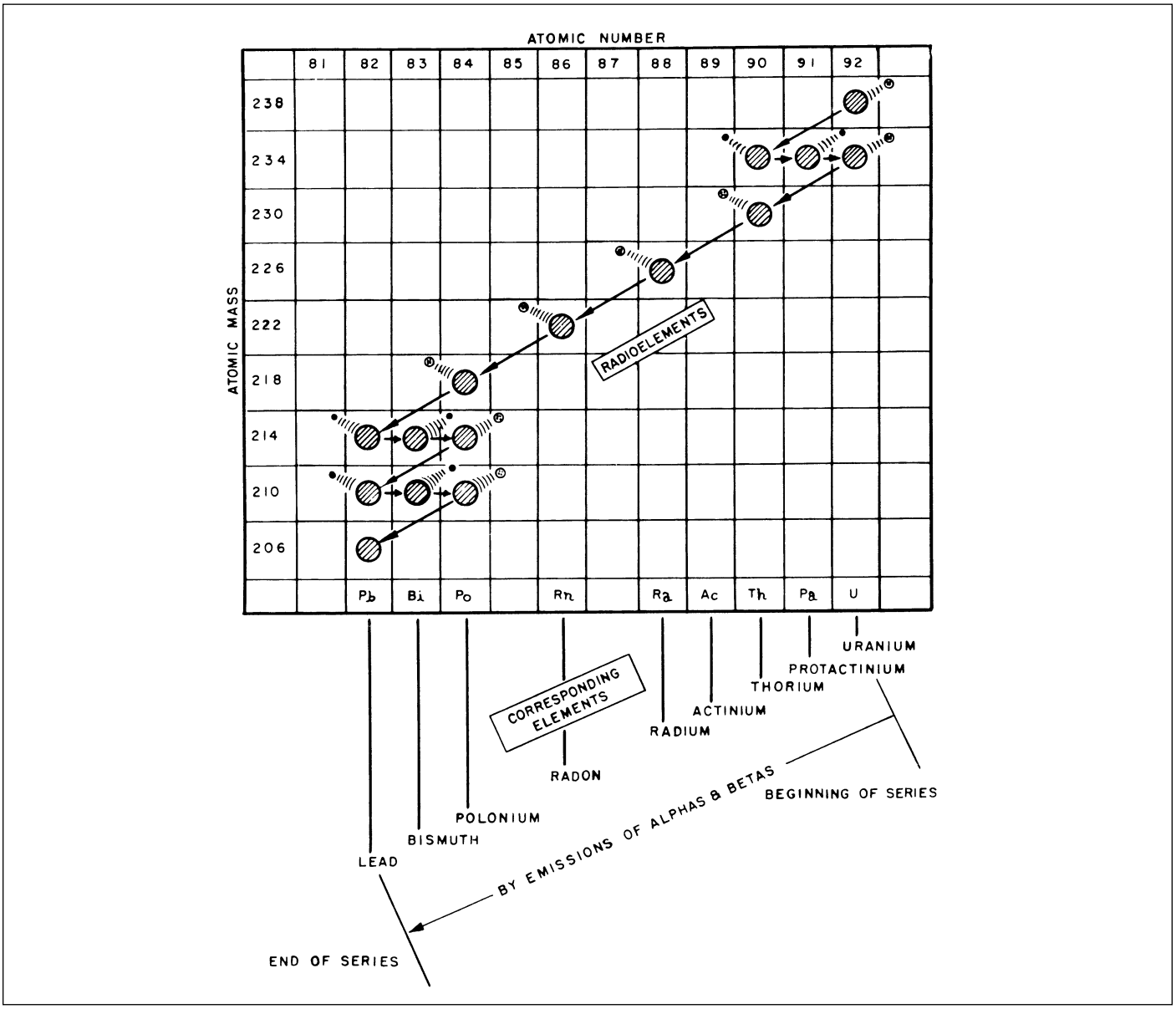


Figure 10–1. The radioactive disintegration scheme of uranium-238 by emissions of alpha- and beta-particles. (Reprinted with permission from *Atomic Radiation,* RCA Service Co., Inc., 1957.)

constitutes a committed effective dose-equivalent equal to the annual occupational effective dose-equivalent limit. This is based on Reference Man.

Atomic number The number of protons (positively charged particles) in the nucleus of an atom. Each element has a different atomic number. The atomic number of hydrogen is 1, that of oxygen 8, iron 26, lead 82, and uranium 92. The atomic number is also called the charge number.

Atomic weight The atomic weight is approximately the sum of the number of protons and neutrons in the nucleus of an atom. This sum is also called the mass number. The atomic weight of oxygen, for example, is approximately 16; most oxygen atoms contain 8 protons and 8 neutrons.

Background radiation The radiation coming from sources other than the radioactive material to be measured. Background radiation is primarily a result of cosmic rays, which constantly bombard the earth from outer space. It also comes from such sources as soil and building materials. Background radiation may vary somewhat depending on location.

Becquerel (Bq) One disintegration per second (dps). This unit is used in measuring the rate of radioactive disintegration. There are 3.7×10^{10} becquerels per curie of radioactivity.

Beta-particle (beta-radiation, β) Beta-particles are small, electrically charged particles emitted from the nucleus of radioactive atoms. They are identical to electrons and have a negative electrical charge of 1. Beta-particles are emitted with various kinetic energies. They pose an internal exposure hazard and are often penetrating enough to cause skin burns.

Bremsstrahlung The electromagnetic radiation associated with the deceleration of charged particles. The term can also be applied to electromagnetic radiation produced by acceleration of charged particles.

Compton effect The glancing collision of a gamma-photon with an orbital electron. The gamma-photon gives up part of its energy to the electron, ejecting the electron from its orbit.

Controlled area A specified area in which exposure of personnel to radiation or radioactive material is controlled. Controlled areas should be under the supervision of a person who has knowledge of and responsibility for applying the appropriate radiation protection practices.

Counter A device for counting nuclear disintegrations, thereby measuring the amount of radioactivity. The electronic signal announcing disintegration is called a count.

Curie (Ci) A measure of the rate at which a radioactive material emits particles. One curie corresponds to 3.7×10^{10} becquerels (disintegrations per second).

Derived air concentration (DAC) The Annual Limit on Intake (ALI) of a radionuclide divided by the volume of air inhaled by Reference Man in a working year (units, Bq/m^3).

Disintegration When a radioactive atom disintegrates, it emits a particle from its nucleus. What remains is a different element. For example, when an atom of polonium 210 disintegrates, it ejects an alpha-particle and changes to a lead 206 atom by this process. When an atom of bismuth 210 disintegrates, it changes to an atom of polonium 210 by beta-particle emission (see Figure 10–1).

Dose A general term denoting the quantity of radiation or energy absorbed by a specified mass. For special purposes, its meaning should be specified, as in *absorbed dose*.

Dosimeter (dose meter) An instrument used to determine the radiation dose a person has received.

Electron A minute atomic particle possessing the smallest possible amount of negative electric charge (–1). Orbital electrons rotate around the nucleus of an atom. Electrons have only about 1/1,820 the mass of protons or neutrons.

Electron volt (eV) A small unit of energy—the amount of energy that an electron gains when it is acted upon by one volt. Radioactive materials emit radiation in energies of up to several million electron volts, or MeV. Gamma-ray energies from radioisotopes range up to 4 MeV or higher. Some are emitted at relatively low energies and are correspondingly less hazardous.

Element All atoms of a given element contain the same number of protons and therefore have the same atomic number. Various isotopes of an element result from a change in the number of neutrons in the nucleus. However, the electrical charge and chemical properties of the various isotopes of an element are identical.

Film badge A piece of masked photographic film worn as a badge for personal monitoring of radiation exposure. It is darkened by penetrating radiation, and radiation exposure can be checked by developing and interpreting the film. The type of masking depends on the type of radiation to be measured.

Gamma-rays (Gamma-radiation, γ) A class of electromagnetic photons emitted from the nuclei of radioactive atoms. Gamma-rays are highly penetrating and present an external radiation exposure hazard.

Gray (Gy) Unit of absorbed radiation dose equal to one joule of absorbed energy per kilogram of matter. 1 Gray = 100 rad.

ICRP International Commission on Radiological Protection and Measurements.

Half-life A means of classifying the rate of decay of radioisotopes according to the time it takes them to lose half their strength (intensity). Half-lives range from fractions of a second to billions of years. Cobalt-60, for example, has a half-life of 5.3 years.

Half-value layer The thickness of a specified substance that, when introduced into the path of a given beam of radiation, reduces the value of the radiation quantity by one-half. It is sometimes expressed in terms of mass per unit area.

Ion An atom or molecule that carries either a positive or negative electrical charge.

Ionizing radiation Electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter. In biological systems, such radiation

must have a photon energy greater than 10 eV. This excludes most of the ultraviolet bands and all longer wavelengths.

Ionization chamber A basic counting device to measure radioactivity.

Isotope These are nuclei that have the same atomic number. Isotopes of a given element contain the same number of protons but a different number of neutrons. For example, the isotope uranium-238 contains 92 protons and 146 neutrons whereas U-235 contains 92 protons and 143 neutrons. Thus the atomic weight, or mass, of U-238 is 3 higher than that of U-235.

Moderator A material used to slow neutrons; it is used, for example, in reactors. Slow neutrons are particularly effective in causing fission. Neutrons are slowed down when they collide with atoms of light elements such as hydrogen, deuterium, and carbon—three common moderators.

Molecule The smallest unit of a compound or element as it exists in nature. A water molecule consists of two hydrogen atoms combined with one oxygen atom, hence the well-known formula H_2O. The element oxygen exists in the form of diatomic molecules, O_2.

NCRP National Council on Radiation Protection and Measurements.

Neutron An atomic particle. The neutron weighs about the same as the proton. As its name implies, the neutron has no electrical charge. Neutrons make effective atomic projectiles for the bombardment of nuclei. Neutrons can also present unique external exposure hazards to personnel.

NRC Nuclear Regulatory Commission.

Nucleus The inner core of an atom. The nucleus consists of neutrons and protons tightly bound together.

Pair production The conversion of a gamma-ray into a pair of particles—an electron and a positron. This is an example of direct conversion of energy into matter, and is quantified by Einstein's famous formula: $E = Mc^2$; energy = mass x velocity of light (squared).

Photoelectric effect Occurs when an electron is ejected from the orbit of an atom by a photon that imparts all of its energy to the electron.

Photon A class, or quantum, of electromagnetic radiation, such as x-rays, gamma-rays, visible light, and radio waves.

Plutonium A human-made heavy element that undergoes fission under the impact of neutrons. It is a useful fuel in nuclear reactors. Plutonium can be produced by the capture of slow neutrons in uranium. It is a highly hazardous alpha-emitter.

Proton An elementary particle found in an atom's nucleus. Its positive charge of +1 is opposite that of the electron.

Quality factor (Q) A function of the linear collision stopping power (L ∞) in water at the point of interest and with a specified energy dependence. It weights the absorbed dose for the biological effectiveness of the charged particles producing the absorbed dose.

Radioactivity The emission of very fast atomic particles or rays by nuclei. Some elements are naturally radioactive; others become radioactive after bombardment with neutrons or other particles. The three major forms of radioactivity are alpha (α), beta (β), and gamma (γ), named for the first three letters of the Greek alphabet.

Radioisotope A radioactive isotope of an element. A radioisotope can be produced by placing material in a nuclear reactor and bombarding it with neutrons. Many fission products are radioisotopes. Radioisotopes are sometimes used as tracers or as energy sources for chemical processing, food pasteurization, and nuclear batteries.

Radium One of the earliest-known naturally radioactive elements. Radium is far more radioactive than uranium and is found in the same ores. It is a highly hazardous alpha-emitter.

Roentgen (R) The amount of x- or gamma-radiation that produces ionization resulting in one electrostatic unit of charge in one cubic centimeter of dry air at standard conditions.

Roentgen absorbed dose (rad) The mean energy per unit of mass imparted by ionizing radiation in a mass. One rad is 100 ergs absorbed per gram. 1 rad = 0.01 Gray.

Roentgen equivalent man (rem) A unit of absorbed dose (in rad) times a quality factor that is used to express the relative biological effect of the particular radiation as compared to gamma-radiation. Personnel exposure limits are often expressed in rem.

Scintillation counter A radiation-counting device that registers the tiny flashes of light (scintillations) that particles produce when they strike certain crystals or liquids.

Shielding A barrier that protects workers from harmful radiations released by radioactive materials. Lead bricks, dense concrete, water, and earth are examples of materials used for shielding.

Sievert (Sv) Unit of absorbed radiation dose (in Gy) times the quality factor of the radiation as compared to gamma-radiation. It is equal to the Gray times the quality factor and is equivalent to 100 rem.

Strontium-90 An isotope of strontium having a mass number of 90. Strontium-90 is an important fission product. It has a half-life of 25 years and is a highly hazardous beta-emitter.

Tracer A radioisotope that is mixed with a stable material. Radioisotopes enable scientists to trace chemical and physical changes in materials. Tracers are widely used in science, industry, and agriculture. For example, when radioactive phosphorus is mixed with a chemical fertilizer, the uptake of radioactive phosphorus from fertilized soil can be measured in the plants as they grow, thereby also indicating the rate of uptake of the fertilizer.

Tritium Often called hydrogen-3. Tritium is an extra-heavy hydrogen whose nucleus contains two neutrons and one proton. It is radioactive as a beta-emitter.

Uranium A heavy metal, the two principal natural isotopes of which are U-238 and U-235. U-235 has the only readily fissionable nucleus that occurs in appreciable quantities in nature, hence its importance as a nuclear reactor fuel. Only one part in 140 of natural uranium is U-235.

X ray Highly penetrating electromagnetic radiation similar to the gamma-ray. X rays are produced by electron bombardment of target materials. They are commonly used to produce shadow pictures (roentgenograms) of dense portions of objects.

TYPES OF IONIZING RADIATION

Radiation is a form of energy. Familiar forms of radiation energy include light (a form of radiation we can see) and infrared (a form of radiation we can feel as heat). Radio and television waves are forms of radiation that we can neither see nor feel. The relationship between the various categories of electromagnetic radiation is shown in Figure 10–2.

Gamma-rays and x rays overlap and occupy a common range in the electromagnetic spectrum. X-radiation is produced in the orbiting electron portion of the atom or from free electrons, whereas gamma-radiation is produced in the nucleus. X rays generally are machine produced and gamma-rays are emitted spontaneously from radioactive materials.

All matter is composed of atoms, each of which has two basic parts: a heavy core, or nucleus, containing positively charged particles called protons and neutral particles called neutrons; and relatively lightweight, negatively charged particles called electrons, which spin around the nuclear core (Figure 10–3). Neutrons and protons were once considered basic particles. However, they have been found to be composed of even smaller particles.

Ionization is an energy transfer process that changes the normal electrical balance in an atom. If a normal atom (electrically neutral) were to lose one of its orbiting electrons (one negative charge), the atom would no longer be neutral. It would have more positive charges than negative charges, making it a positive ion. Electrons thus removed are called free electrons. If the free electron then attaches to another atom, that atom would become a negative ion. The positive and negative ions thus produced are known as an ion pair.

The term *nuclear radiation* describes all forms of radiation energy that originate in the nucleus of a radioactive atom. In addition to gamma-rays, fast-moving particles are sometimes emitted from radioactive atoms.

Some materials are naturally radioactive; others can be made radioactive in a nuclear reactor or accelerator. Some nonradioactive atoms can be converted to radioactive atoms when an extra neutron is captured by a nucleus. The resulting radioactive atom is unstable because of the extra energy that the neutron added to the nucleus. The excited, or radioactive, atoms get rid of their excess energy and return to a stable state by emitting subatomic particles and gamma-rays from the nucleus. The most important of these particles are alpha-particles, beta-particles, and neutrons.

The hazardous properties of radioactive materials are usually thought of in terms of nuclear radiation. All types of radiation share the common properties of being absorbed and transferring energy to the absorbing body.

The most commonly encountered types of ionizing radiation are alpha-, beta-, and neutron particles and x- or gamma-electromagnetic radiation. Other types of ionizing radiation are encountered in specialized facilities.

Alpha-Particles

Alpha-particles originate in the nuclei of radioactive atoms during the process of disintegration. These particles consist of a cluster of 2 protons and 2 neutrons (giving a mass number of 4, which is structurally the same as the nucleus of a helium atom). Alpha-particle emission changes an atom to one having an atomic number lowered by 2 and an atomic mass lowered by 4. Uranium-238 changes to thorium-234 by emission of an alpha particle. Alpha-particles, on slowing down, combine with electrons from the material through which they are passing, and thus become helium atoms.

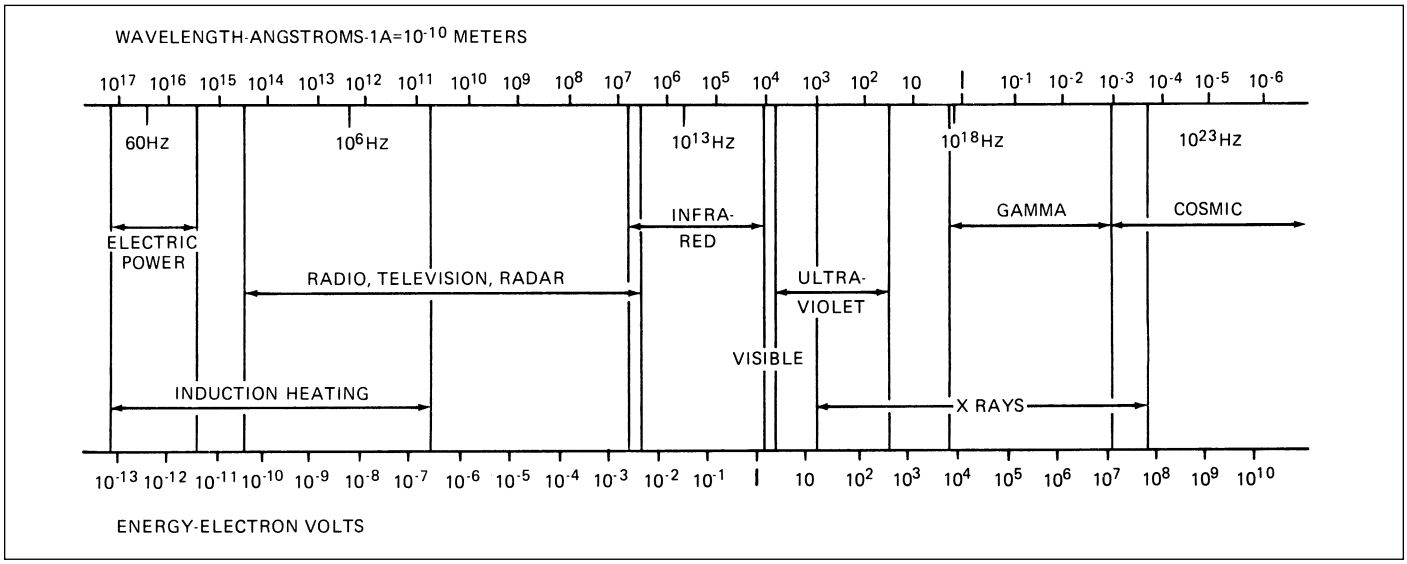


Figure 10–2. Electromagnetic spectrum illustrates energy and wavelength of the various categories of electromagnetic radiation.

The mass and electrical charge characterize the hazardous properties of alpha-particles. They have a positive charge of 2 units and interact electrically with human tissues and other matter. Alpha-particles range in energy to over 7 MeV. Because of their large mass and the dense ionization along their path through a material, they travel only a short distance. Their range is at most about 4 in. (10 cm) in air. They are stopped by the dead, outer layer of the skin, a film of water, a sheet of paper, or other paper-thin material (Figure 10–4).

To detect alpha-particles with a radiation survey meter, the instrument probe must be held close to the source, and the window on the probe must be very thin and designed specifically for alpha-detection.

Alpha-particles are produced by elements with high atomic numbers (Figure 10–1). Alpha-emitters are hazardous when taken into the body. Because they are chemically similar to calcium in their action within the body, some alpha-emitters are absorbed into the bones, where they remain for long periods of time. As they disintegrate, they emit alpha-particles, which can damage tissue. Other alpha-emitters are not bone seekers but concentrate in body organs such as the kidney, liver, lungs, and spleen.

If the alpha-emitting material is kept outside the body, little damage results because generally alpha-particles cannot penetrate the outermost, dead layer of skin. Care is needed to avoid inhalation or ingestion of alpha-radioactive materials and to avoid puncture wounds by items contaminated with alpha radioactivity. Alpha-emitters are considered to be only internal radiation hazards.

Beta-Particles

Beta-particles are electrically charged particles ejected from the nuclei of radioactive atoms during disintegration. They generally have a negative electrical charge of 1 unit and the same mass as an electron. Negative beta-particle emission causes the disintegrating atom to change into an element of a higher atomic number. Thus, strontium-90 changes to yttrium-90 on disintegration with ejection of a beta-particle (electron) from a neutron in the nucleus. The atomic number of the atom (the number of protons in the nucleus) is changed from 38 to 39 by the beta-particle emission from a neutron, causing it to gain a proton. (A neutron, by emitting a beta-particle, becomes a proton.)

Particles similar to beta-particles, with the same mass as electrons but with a positive unit charge, are called positrons, which can also be ejected from nuclei by disintegration. A proton from which a positron is emitted subsequently becomes a neutron, and the atomic number of the atom is reduced by 1. However, positrons are readily annihilated by combination with electrons, yielding gamma-radiation.

Beta-particles do not penetrate to the depth that x rays or gamma-radiation of similar energy do (Figure 10–4). Their maximum range in wood is about 1.5 in. (4 cm), and they can penetrate the human body to a depth of 0.1–0.5 in. (0.2–1.3 cm).

Skin burns result from extremely high doses of beta-radiation, because it requires only about 70 keV (1 keV = 0.001 MeV) of energy for a beta-particle to penetrate the dead, outer layer of skin. Beta-emitters are internal radiation hazards when taken into the body.

Beta-particles have a broad distribution of energies ranging from near zero up to the maximum value specific for the particular radionuclide. The maximum range in air of the beta-particles emitted from one radionuclide may be 6 in. (15 cm), and the maximum range of emissions from another radionuclide may be 60 ft (18 m). The higher-energy beta-particles penetrate farther, transfer more energy, and cause more damage.

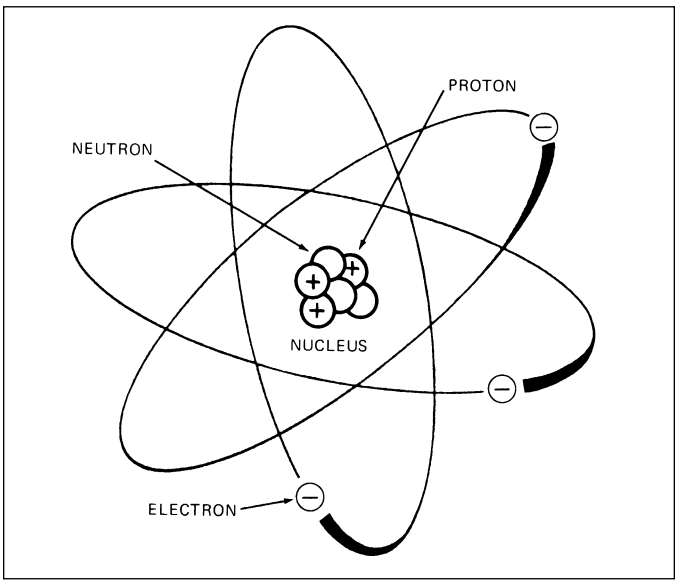


Figure 10–3. Basic model of the atom. The atom illustrated here is lithium-6.

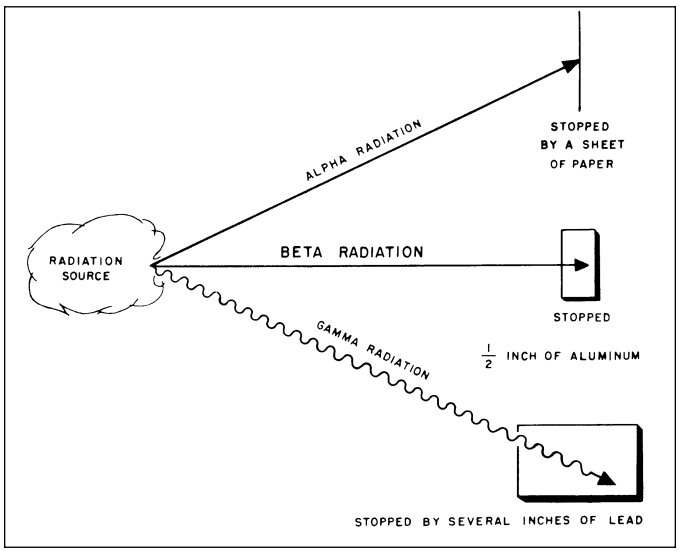


Figure 10–4. Relative penetrating power of alpha-, beta-, and gamma-radiation. (Reprinted with permission from *Atomic Radiation,* RCA Service Co., Inc., 1957.)

Beta-particles, or high-energy electrons, are emitted from a wide range of light and heavy radioactive elements. Beta-particles are much smaller than alpha-particles, and some have a velocity approaching the velocity of light. The energy level of beta-particles can be 4 MeV or higher. The energy range of beta-particles is similar to that of gamma-rays.

Beta-particles have an electrical charge of 1 unit, which tends to limit their penetration range somewhat, but penetration is greater than that of the doubly charged alpha-particles. Beta-particles are relatively more hazardous externally than alpha-particles because their penetration power is greater.

When a beta-particle is slowed down or stopped, secondary x-radiation, known as bremsstrahlung, may be produced.

Light metals such as aluminum are preferred for shielding from beta-particles because light metals produce less bremsstrahlung radiation. Plexiglas™ is another shielding material that is effective against such radionuclides as P-32. Common beta-radiations have ranges of less than 30 ft (9 m) in air. Depending on their energy, they can be stopped by the walls of a room or by a sheet of aluminum 0.5 in. (1.3 cm) thick.

Neutrons

Neutrons are not encountered as commonly as alpha- and beta-particles. The neutron particle, as its name implies, has no electrical charge. Neutrons exist within the nuclei of all atoms except those of the lightest isotope of hydrogen.

Neutrons are released on disintegration of certain radioactive materials (the fissionable isotopes). They have long or short ranges in air depending on their kinetic energy, which in turn depends on the method by which a particular neutron was produced. Furthermore, their range depends on the characteristics of the material through which they pass, the way the atoms of that material interact with the neutrons, and the kind of collisions that occur. In human tissue, the average depth of penetration of neutrons varies from about 0.25 in. (0.6 cm) to several inches (centimeters), depending on the neutrons' energy.

Very high-energy neutrons collide with atoms of the material through which they are passing, often breaking these nuclei into high-energy fragments. The neutron itself is unstable and emits a beta-particle as it decays to a proton. Interaction with the atoms of the material through which neutrons pass is the main way neutrons are removed from a beam.

Absorption of neutrons results when neutrons are deflected by, or collide with, nuclei. They collide repeatedly, which slows them down. The loss of energy by neutrons that suffer such collisions leads to an increased probability of absorption by a nucleus. This absorption process is called neutron capture.

In the human body, most of the captures that occur take place in hydrogen or nitrogen atoms. The result is that the nucleus of the atom is in an excited state. That is, an excess of energy is available. An atom can exist in this state only for a short period of time and returns to the ground (unexcited) state by releasing the excess energy. In the process, a proton, gamma-ray, beta-particle, or alpha-particle is emitted, depending on what type of atom captures the neutron. Because it is these secondary emissions that produce damage in tissue, the task of determining the neutron dose is difficult. The health hazard that neutrons present arises from the fact that they cause the release of secondary radiation.

Human exposure to neutrons occurs around reactors, accelerators, and sources designed to produce neutrons. Determination of the extent of damage from neutron exposures must be made by highly skilled people using specialized equipment. The amount of harm caused by a dose is dependent not only on the number of neutrons absorbed but also on their energy distribution.

X-Radiation

X-radiation is commonly thought of as electromagnetic radiation produced by an x-ray machine. When high-speed electrons are suddenly slowed down when they strike a target, they lose energy in the form of x-radiation. In an x-ray machine, the voltage across the electrodes of the vacuum tube determines the energy of the electrons, which principally determines the wavelength and penetrating quality of the resulting x rays.

The character of x-radiation is also affected by the target material inside the x-ray tube. That is, the wavelength of a portion of the x-radiation is affected by the kind of material composing the target. Because the electrons strike and interact at various speeds, the x-ray beam has a variety of wavelengths and energies. The energy of an x ray is inversely proportional to its wavelength; the more energy an x ray possesses, the shorter its wavelength.

The extent of penetration of x rays depends on wavelength and the material being irradiated. The x rays of short wavelength are called hard, and they penetrate several centimeters of steel. The x rays of long, or soft, wavelengths are less penetrating. The power to penetrate through matter is called the *quality*. *Intensity* is the energy flux density. The physical properties of a beam of x or gamma-rays are often summarized by the two concepts of intensity and quality.

The range of penetration can be expressed in terms of *half-value layer*. This is the thickness of material necessary to reduce the incident radiation by one-half. The half-value layers for x-radiation range up to several centimeters of concrete (Table 10–A).

Gamma-Radiation

Gamma-radiation is similar to x-radiation in that it is also electromagnetic and ionizing. In fact, it is identical to x-radiation except for its source being the nucleus of an atom. X-radiation is electromagnetic radiation that originates outside the nucleus.

Table 10–A. ***Half-Value Layer for Five Shielding Materials***

Material	*Cobalt-60*	*Cesium-137*
Lead	1.24 cm	0.64 cm
Copper	2.10 cm	1.65 cm
Iron	2.21 cm	1.73 cm
Zinc	2.67 cm	2.06 cm
Concrete	6.60 cm	5.33 cm

Note: 1 cm= 0.394 in.

Radioactive materials, by definition, spontaneously emit one or more characteristic radiations, possibly including gamma-radiation. The radiation comes from an excited or unstable nucleus of an atom.

A gamma-ray emitted by a given radionuclide has a fixed energy specific to that radionuclide (Table 10–B). Gamma-rays from various radionuclides cover a wide range of wavelengths, or energies. They present an external exposure problem because of their deep penetration. The half-value layer of shielding for 1.0 MeV gamma- or x-radiation is slightly more than 0.5 in. (1.3 cm) of steel.

Radioactive Decay Calculations

Radioactive materials decay—that is, they give off alpha-particles, beta-particles, and photon energy and lose a portion of their radioactivity with a characteristic half-life. The half-life can be brief, for example, 55 seconds for R-220; a matter of days, such as 8 days for I-131; or many years, such as 4.51 billion years for U-238. The amount of radioactivity remaining after a given period of time is calculated as follows:

Equation 1

$$A = A_0\, e^{\left(-0.693\ \frac{t}{T_{1/2}}\right)} = \frac{A_0}{e^{\left(0.693\frac{t}{T_{1/2}}\right)}}$$

where A = radioactivity remaining after time t
A_0 = radioactivity at a given original time
e = base of natural logarithms (2.718)
t = elapsed time
$T_{1/2}$ = half-life of the radionuclide

Note that radioactivity and time units must be consistent: If is given in curies (Ci), then A should also be in curies. If $T_{1/2}$ is given in years, then t must also be in years.

Example

What radioactivity would remain from 1 Ci (curie) of Co-60 (5.24 years half-life) after a 20-year period?

Solution

Equation 2

$$A = \frac{1\text{ Ci}}{e^{\left(\frac{0.693\ [20y]}{5.24y}\right)}} = \frac{1\text{ Ci}}{e^{(2.645)}} = \frac{1\text{ Ci}}{14.08} = 0.071\text{ Ci}$$

The amount of radioactivity remaining from 1 Ci of cobalt-60 after 20 years is 0.071 Ci (71 mCi).

Note that in some instances radioactive decay results in another radioisotope, and there is a decay chain of radioisotopes before a nonradioactive (stable) isotope is formed (see Figure 10–1). The published tables of radioisotopes should be checked to determine the decay chains.

BIOLOGICAL EFFECTS OF RADIATION

The human body can apparently tolerate a certain amount of exposure to ionizing radiation without its overall functions being impaired as a result. We are continuously exposed to ionizing radiation from natural sources such as cosmic radiation from outer space and from radioactive materials in the earth and materials around us and in us. This "background radiation" is part of our normal environment; we have evolved under its effects and are continuously exposed to it. The average annual dose from background radiation varies across the country, but it is commonly around 300 mR/y.

One fundamental property of ionizing radiation is that when it passes into or through a material, it transfers energy by the ionization process. The intensity of radiation to which a material is subjected is known as the radiation field. The term *dose* is generally used to express a measure of radiation that a body or other material absorbs when exposed to a radiation field.

If the incoming and outgoing energies are almost identical in nature and amount, then little energy is transferred and the dose is small.

External radiation sources, which are located outside of the body, present an entirely different set of conditions than radionuclides that have entered the body. Once inside the body, radionuclides are absorbed, metabolized, and distributed throughout the tissues and organs according to their chemical properties. Their effects on organs or tissues depend on the type and energy of the radiation and their residence time within the body.

The effects of irradiation on living systems are studied by looking for effects on the living cells, for changes in biochemical reactions, for evidence of production of disease, and for changes in life or normal growth patterns (Figures 10–5 and 10–6).

Interpretation of such findings is not simple. Extensive research in this field continues to be conducted in many laboratories.

The effect of ionizing radiation on living tissue is generally assumed to be almost entirely due to the ionization process, which destroys the capacity of reproduction or division in some cells and causes mutation in others (Figure 10–6). The human body is a complex chemical machine that constantly produces new cells to replace those that have died or been damaged. The body has a tremendous capability for repairing cell damage. Therefore, our survival depends on our ability to keep cell damage within the body's repair capabilities.

Table 10–B. *Isotopes Commonly Available, Listed by Increasing Half-Life*

Half-Life	Element and Symbol	Atomic Number	Mass Number	Gamma-Radiation Energy (MeV)
88 days	Sulfur (S)	16	35	none
115 days	Tantalum (Ta)	73	182	0, 0.68, .10, .15, .22, 1.12, 1.19, 1.22
120 days	Selenium (Se)	34	75	0.12, .14, .26, .28, .40
130 days	Thulium (Tm)	69	170	0.084
138 days	Polonium (Po)	84	210	0.80
165 days	Calcium (Ca)	20	45	none
245 days	Zinc (Zn)	30	65	1.12
270 days	Cobalt (Co)	27	57	0.12, .13
253 days	Silver (Ag)	47	110	0.66, .68, .71, .76, .81, .89, .94, 1.39
284 days	Cerium (Ce)	58	144	0.08, 1.34
303 days	Manganese (Mn)	25	54	0.84
367 days	Ruthenium (Ru)	44	106	none
1.81 years	Europium (Eu)	63	155	0.09, .11
2.05 years	Cesium (Cs)	55	134	0.57, .60, .79
2.6 years	Promethium (Pm)	61	147	none
2.6 years	Sodium (Na)	11	22	1.277
2.7 years	Antimony (Sb)	51	125	0.18, .43, .46, .60, .64
2.6 years	Iron (Fe)	26	55	none
3.8 years	Thallium (Tl)	81	204	none
5.27 years	Cobalt (Co)	27	60	1.3, 1.12
12.46 years	Hydrogen (H)	1	3	none
12 years	Europium (Eu)	63	152	0.12, .24, .34, .78, .96, 1.09, 1.11, 1.41
16 years	Europium (Eu)	63	154	0.123, .23, .59, .72, .87, 1.00, 1.28
28.1 years	Strontium (Sr)	38	90	none
21 years	Lead (Pb)	82	210	0.047
30 years	Cesium (Cs)	55	137	0.661
92 years	Nickel (Ni)	28	63	none
1602 years	Radium (Ra)	88	226	0.186
5730 years	Carbon (C)	6	14	none
2.12×10^5 years	Technetium (Tc)	43	99	none
3.1×10^5 years	Chlorine (Cl)	17	36	none

(Reprinted from *Radiological Health Handbook,* revised ed., January 1970. U.S Dept. of Health & Human Services, Rockville, MD.)

Ionization strips electrons from atoms and breaks their chemical bonds with other atoms. A simple molecule such as that of water recombines after ionization. This, however, is not the case in a complicated living cell. Here, ionization can result in many possible atomic recombinations. The rupture of a few bonds in the elaborate structure of the molecules of the living cell can have profound effects.

Types of Injuries

We started to learn about the effects of radiation on humans in 1895, when Wilhelm Roentgen discovered the x ray. Radiation from uranium was discovered by Antoine-Henri Becquerel in 1896. Alpha- and beta-particles and gamma-rays were identified shortly thereafter, and the neutron was discovered in 1930. Injurious effects of radiation were experienced by these early workers.

There are two points of view for consideration of the injurious effects of ionizing radiation: the somatic effects (injury to individuals) and the genetic effects, which are passed on to future generations.

The degree of injury inflicted on an individual by radiation exposure depends on such factors as the total dose, the rate at which the dose is received, the kind of radiation, and the body part receiving it.

Tissues such as the bone marrow, where blood cells are produced, the lining of the digestive tract, and some cells of the skin are more sensitive to radiation than those of bone, muscle, and nerve.

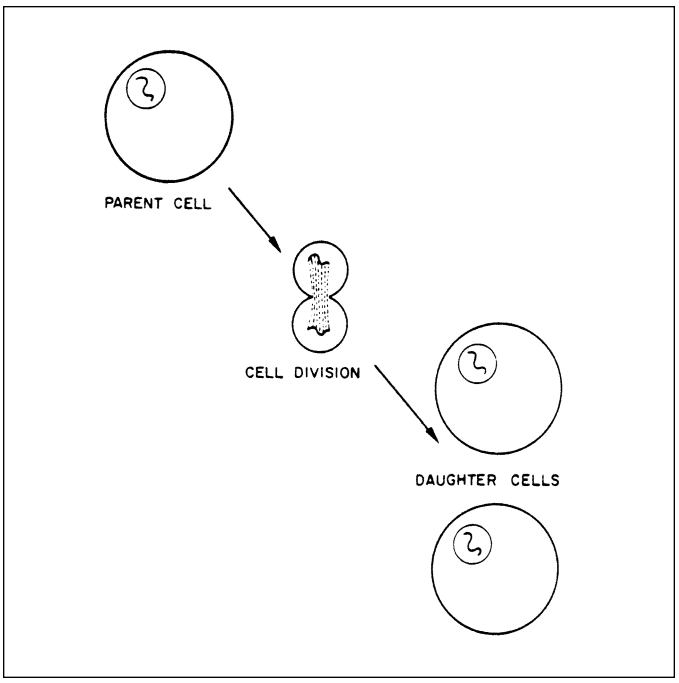


Figure 10–5. Normal cell division. (Reprinted with permission from *Atomic Radiation,* RCA Service Co., Inc., 1957.)

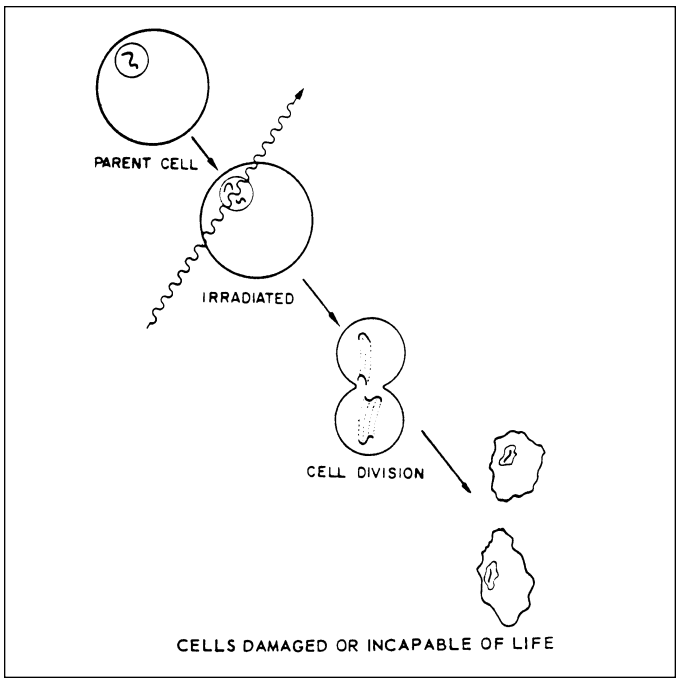


Figure 10–6. Damage or death of cells after division of irradiated parent cell. (Reprinted with permission from *Atomic Radiation,* RCA Service Co., Inc., 1957.)

In general, if the total amount of radiation is received slowly over a long period of time, a larger dose is required to produce the same degree of damage than if the same total is received over a short period. If the rate at which the dose is received is low enough, the body recovery processes are able to keep abreast of the slight damage.

Some relatively small doses have no effect if given only once but will shorten life span and produce abnormalities if continued long enough. The time between exposure and the first signs of radiation damage is called the latent period. The larger the dose, the shorter the latent period.

The various tissues and organs of the body are not affected equally by equal irradiation. Their responses vary considerably. For radiation protection purposes, it is essential that the dose to the most sensitive organs be given primary consideration.

Over the years, allowable radiation levels have been consistently reduced, as researchers have obtained more information on the effects of radiation exposure and as judgments involving acceptable risks have become more conservative. As radiation was applied to humans for healing purposes, effects such as skin redness, dermatitis, and skin cancer were noted, as were hair loss and eye inflammation. It was found that the incidence of cancer and certain blood diseases was higher among radiologists than would be expected for a chance distribution in the population studied.

The pool of health experience data was obtained from the following sources:

- ➢ Early radiation workers
- ➢ Medical personnel who routinely administered radiation for diagnostic and therapeutic purposes
- ➢ Patients who were treated with radiation
- ➢ A group of workers who painted dials with luminous paints containing radium
- ➢ Studies of Japanese atomic bomb survivors

With data collected from these sources, it became apparent that exposure to ionizing radiation was associated with a higher than normal incidence of certain diseases such as skin, lung, and other cancers; of bone damage; and of cataracts. There was also some evidence of life shortening.

Geneticists consider the population as a whole rather than particular individuals. Their concern is the effect of radiation on future generations. Radiation damage to human reproductive materials can be transmitted to succeeding generations.

Genetic damage is sometimes caused by disease or toxic chemicals as well as by ionizing radiation. Birth defects are usually the result of defective genes, but it is not possible at this time to determine what caused the damage to a given defective gene.

Relating Dosage to Damage

Extensive work has been done in an attempt to relate radiation dose to resulting damage. Researchers have done a great deal of laboratory work with various biological systems (both plants and animals) in order to learn more about the conditions of irradiation, the effects it produces, and the relative effectiveness of the kinds and energies of radiation.

These studies provide the basis for determining maximum permissible levels of exposure. The maximum permissible levels denote the maximum radiation dose that can

be tolerated with little chance of later development of adverse effects. The BEIR V report from the National Academy of Sciences listed in the Bibliography at the end of the chapter gives information on biological effects of ionizing radiation.

STANDARDS AND GUIDES

Maximum permissible levels of external and internal radiation have been published by the National Council on Radiation Protection and Measurements (NCRP), with exposure limits as shown in Table 10–C. The Nuclear Regulatory Commission establishes "Permissible Doses, Levels, and Concentrations" in *10 CFR 20*. (See Bibliography at the end of the chapter.)

Guides for maximum permissible external exposure to ionizing radiation have also been published by the International Commission on Radiological Protection and Measurements (ICRP). The 2000 Threshold Limit Value® is identical to the ICRP exposure guides. (See Appendix B for the TLV.)

Levels far below the maximum exposure limits recommended by the Federal Radiation Council can generally be achieved with no substantial inconvenience. The accepted practice is to keep radiation exposure as low as reasonably achievable (ALARA). Present limiting values are given separately for protection against different types of effects on health and apply to the sum of doses from external and internal sources of radiation. For cancer and genetic effects, the limiting value is specified in terms of a derived quantity called the effective dose equivalent. The effective dose equivalent received in any year by an adult worker should not exceed 5 rem (0.05 Sv). For other health effects, the limiting values are specified in terms of the dose equivalent to specific organs and tissues. (See *Recommendations for the Safe Use and Regulation of Radiation Sources in Industry, Medicine, Research and Teaching,* ICRP Report 102, 1990.)

Occupational dose equivalents to individuals under the age of 18 should be limited to educational and training purposes and should be less than 0.1 rem per year (1 mSv per year) (NCRP).

There is disagreement on the magnitude, extent, and cause of effects, if any, at exposures below the guide levels. Much of this discussion centers on theory, rather than on measured cause and demonstrated effect in human beings.

Because of the sensitivity of the fetus to radiation damage, the NCRP has recommended an occupational monthly equivalent dose limit of 50 mrem (0.5 mSv) to fetuses (excluding medical and natural background radiation) once pregnancy is known. The reason for the lower limit of exposure is that rapidly dividing cells are more susceptible to radiation damage than are mature cells. Women of childbearing age who may be exposed to

Table 10–C. *NCRP Recommendations on Limits for Exposure to Ionizing Radiation (Excluding Medical Exposures)*

A. Occupational exposure		
1. Effective dose limits		
a. Annual	5 rem	50 mSv
b. Cumulative	1 rem × age	10 mSv × age
2. Equivalent dose annual limits for tissues and organs		
a. Lens of eye	15 rem	150 mSv
b. Skin, hands, and feet	50 rem	500 mSv
B. Guidance for emergency occupational exposure* (see Section 14 of NCRP report 116)		
C. Public exposure (annual)		
1. Effective dose limit, continuous or frequent exposure*	100 mrem	1 mSv
2. Effective dose limit, infrequent exposure*	500 mrem	5 mSv
3. Equivalent dose limits for tissues and organs		
a. Lens of eye	1.5 rem	15 mSv
b. Skin, hands, and feet	5 rem	50 mSv
4. Remedial action for natural sources:		
a. Effective dose (excluding radon)	>500 mrem	>5 mSv
b. Exposure to radon decay products		>7 x 10^{-3} Jh m^{-3}
D. Education and training exposures (annual)*		
1. Effective dose limit	100 mrem	1 mSv
2. Equivalent dose limit for tissues and organs		
a. Lens of eye	1.5 rem	15 mSv
b. Skin, hands, and feet	5 rem	50 mSv
E. Embryo/fetus exposures (monthly)*		
1. Equivalent dose limit	50 mrem	0.5 mSv
F. Negligible individual dose (annual)*	1 mrem	0.01 mSv

Note: Recommendations on WR and WT are in tables 4.2 and 5.1 of NCRP report 116.

* Sum of external and internal exposures but excluding doses from natural sources.

(From NCRP Report No. 116, Limitation of Exposure to Ionizing Radiation, 1993, with English units added for comparison to metric units.)

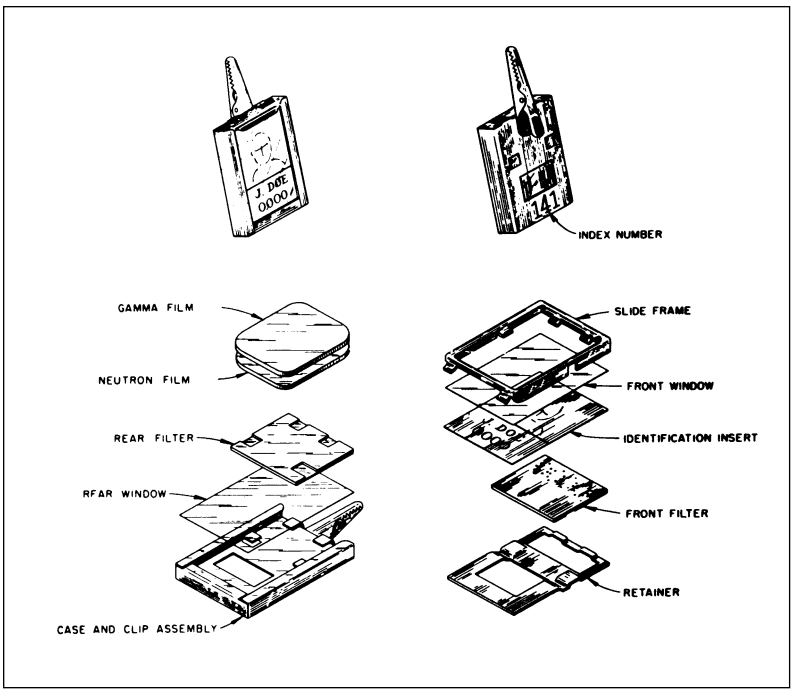


Figure 10–7. Exploded view of radiation film badge. Upper left is front view; upper right is back view.

radiation should be informed of the need to protect the fetus from excessive or unnecessary radiation exposure. In the event that occupational exposure exceeds PELs, action should be taken to reduce the exposures to within the guidelines. If this is not practicable, it is necessary to transfer the female worker out of the radiation exposure area for the duration of the pregnancy.

In summary, radiation dose limits established by any official organization or government body that has authority with respect to the user should be considered upper limits; the objective should be to keep exposure as low as reasonably achievable.

The NCRP recommends a whole-body dose limit of 5 rem per year (50 mSv) for occupational exposure. Cumulative exposure is not to exceed 1 rem (0.01 Sv) multiplied by the individual's age in years.

For further explanation of radiation protection standards and guides, refer to the Bibliography at the end of this chapter.

MONITORING INSTRUMENTS

There are a variety of detectors and readout devices used for monitoring and measuring radiation. None is universally applicable, and selection of the most appropriate detector or detectors for each radiation measurement (or type of measurement) is a matter of great importance.

Radiation monitoring involves the routine or special measurement of radiation fields in the vicinity of a radiation source, measurement of surface contamination, and measurement of airborne radioactivity. Such monitoring procedures are sometimes called radiation surveys.

Film Badges

The film badge, worn on the outer clothing, is an example of a personal radiation monitor for gamma-, x-, and high-energy beta-radiation. It consists of a small piece of photographic film wrapped in an opaque cover and supported with a metal backing. It can be pinned to the clothing or worn as a ring. Radiation interacts with the silver atoms in the photographic film to affect (expose) the film the same way that light rays do. The badge is removed at regular intervals and the film developed. The amount of darkening of a film is then compared to a control film, that was not exposed to radiation during the same time period, to determine the amount of radiation exposure. Figure 10–7 shows a typical film-badge arrangement for monitoring personnel; the film badge provides a permanent record of dosage.

Thermoluminescence Detectors

Thermoluminescence detectors (TLDs) have come into widespread use for radiation exposure monitoring for gamma-, x-, and beta-radiation. These dosimeters can be worn by the person as body badges or finger rings. Most commonly they are small chips of lithium fluoride. A major advantage of the TLDs is that for x- and gamma-radiation, they essentially require no energy source to operate in exposure from 20 keV up. The ionizing radiation energy absorbed by the TLD displaces electrons on it from their ground state (valence state). The electrons are trapped in a metastable state but can be returned to the ground state by heating. When electrons return to the ground state, light is emitted. A TLD readout instrument is used for precise control of heating the chip and measuring the light that is then emitted from it. The amount of light released is related to the absorbed radiation dose and, in turn, to the radiation exposure of the individual. Because the stored energy is released on readout, the readings cannot be repeated. It is therefore common practice to include two or more chips in

Figure 10–8. A health physics technician wearing a thermoluminescence detector attached to a neck strap and an electronic alarming dosimeter on his right shirt pocket.

a dosimeter. Figure 10–8 shows a health physics technician wearing a TLD dosimeter attached to a neck strap. Neck straps are available with friction connectors and quick release clips for safe and efficient use.

Pocket Dosimeters

The pocket dosimeter is a direct-reading portable unit shaped like a pen with a pocket clip. It is generally used to measure x- and gamma-radiation (although it may respond to beta-radiation).

A dosimeter consists of a quartz fiber, a scale, a lens to observe the movement of the fiber across the scale, and an ionization chamber. The fiber is charged electrostatically until it reaches zero on the scale. When the dosimeter is exposed to radiation, some of the air atoms in the chamber become ionized. This allows the static electricity charge to leak from the quartz fiber in direct relationship to the amount of radiation present. As the charge leaks away, the fiber deflects to some new position on the scale that indicates the amount of radiation exposure.

The main advantage of the pocket dosimeter is that it allows the individual to determine the radiation dose while working with radiation, rather than waiting until after periodic processing of a film badge or thermoluminescent dosimeter.

Electronic Alarm Dosimeters

Personal electronic alarm dosimeters are used to monitor the presence of x- and gamma-radiation. These units, usually Geiger–Mueller tubes, have an automatic audible alarm if significant exposure rates are encountered. They can also be set to alarm at a preset total integrated exposure. With a reader, they can provide a digital readout of exposure. They are compact and lightweight to allow for wearing them on clothing, similar to a pager. See Figure 10–8 showing a health physics technician wearing an electronic alarming dosimeter on his right shirt pocket.

Ionization Chambers

Radiation can be measured very conveniently and accurately by measuring the ionization in a small volume of air. If two plates or electrodes with an electrical potential between them are placed in a container filled with air, an ionization chamber is formed. If the ionization chamber is exposed to a beam of radiation, a current flows in the circuit because the electrons that are knocked out of the air atoms by the radiation are attracted by the positive electrode. In other words, ionized air becomes conductive (Figure 10–9).

The ionization chamber measures ionization directly and is energy independent. These units can measure gamma-, x-, beta-, and, if the window is thin enough, alpha-radiation. It is a very useful and popular tool for radiation safety work. Use of an ionization chamber instrument for gamma-radiation measurements is illustrated in Figures 10–10 and 10–11.

Geiger–Mueller Counters

A Geiger–Mueller counter is used for beta-, gamma-, and x-radiation survey measurements because it is capable of detecting very small amounts of radiation. It is especially sensitive to beta-radiation. It uses an ionization chamber but it is filled with a special gas and has a greater voltage supplied between its electrodes. It only takes a very small number of

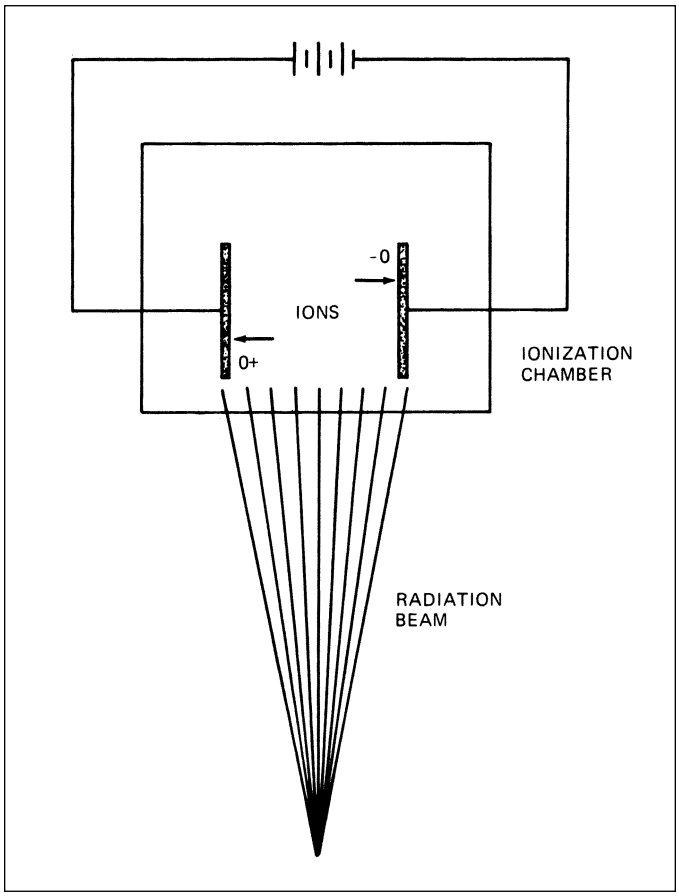


Figure 10–9. Diagram of an ionization chamber.

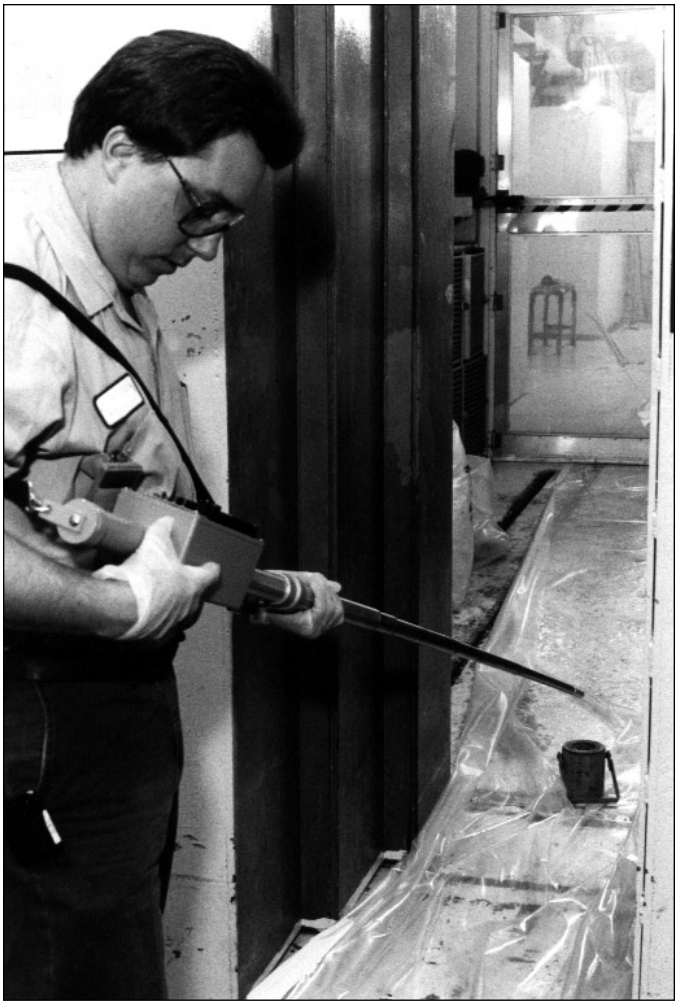


Figure 10–10. Health physics technician using telescopic high-range ion chamber survey instrument. (Note the thermoluminescent dosimetry badge on shirt pocket and electronic alarm dosimeter on trouser pocket.)

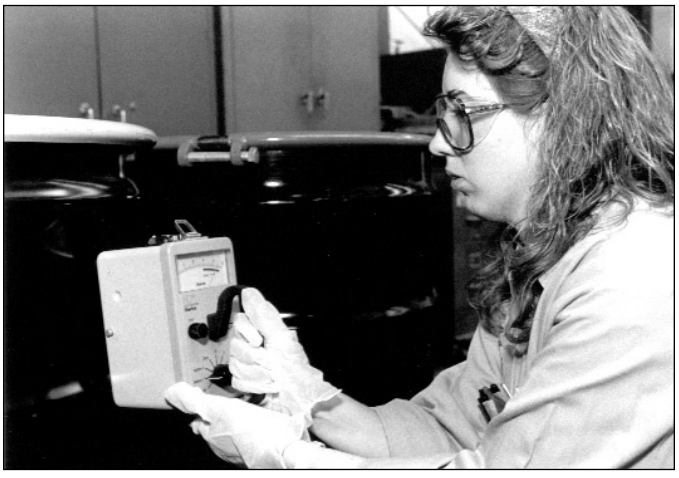


Figure 10–11. Health physics technician taking exposure rate readings with an ion chamber survey instrument.

ions to put it into discharge. Electrons are freed by the initial ionization process, and they acquire enough extra energy from the applied voltage to create more ions. This instrument does not give a uniform response for different radiation energy levels and is accurate only for the type of radiation energy for which it is calibrated. A radiation survey with a Geiger–Mueller counter is shown in Figure 10–12.

Other Monitoring Instruments

Scintillator types of radiation-monitoring instruments are designed to measure light flashes created by the interaction of ionizing radiation and scintillator materials. This type of survey instrument, which is useful for sensitive measurements of alpha- and beta-gamma–radiation, is shown in Figure 10–13.

Calibration

Usually, the calibration of radiation meters is a laboratory procedure that should be carried out by qualified experts. Under certain circumstances, however, it is possible and permissible to calibrate meters by comparing a radiation-measuring instrument with a standard radiation source of known output.

Figure 10–12. Use of a Geiger–Mueller counter. (Courtesy Argonne National Laboratory.)

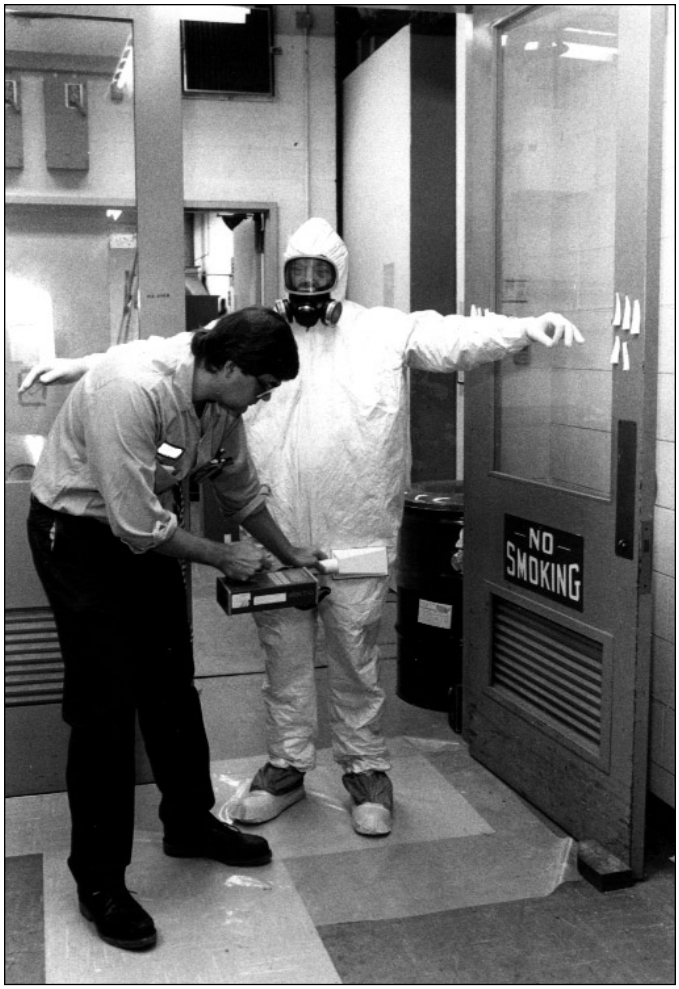


Figure 10–13. Health physics technician monitoring protective clothing after removal of outer protective suit. Survey meter has a dual plastic scintillator to detect alpha-, beta-, and gamma-radioactivity.

Consult up-to-date manuals and become familiar with regulations concerning the use and calibration of radiation-monitoring devices.

BASIC SAFETY FACTORS

For external radiation exposure hazards, the basic protection measures are associated with time, distance, and shielding.

Time

The longer the exposure, the greater the chance for radiation injury. Because there is a direct relationship between exposure dose and duration of exposure, reducing the exposure time by one-half reduces the dose received by one-half.

A common practice is to reduce the exposure time and thus the exposure. From the knowledge of the dose rate in a given location and the maximum dose that is acceptable for the time period under consideration, the maximum acceptable exposure time can be calculated. If the exposure rate is 2.5 mrem/h (0.025 mSv/h), 40 hours results in 100 mrem (1 mSv) exposure. If the exposure rate is 10 times higher, then the time must be reduced to one-tenth (to 4 h) for the same dose (Figure 10–14).

In practice, the dose received in accomplishing a task can be spread over several employees so that no one person's exposure exceeds the guidance levels. Only the minimum necessary exposure should be planned for a work task. Exposure rate is measured with one of several types of instruments. Direct-reading dosimeters are available, as are those that emit alarm sounds at a preset exposure rate and at an accumulated exposure setting.

Distance

The inverse square law can be applied to determine the change in external penetrating radiation exposure with change in distance from a radiation source. Figure 10–15 indicates that by doubling the distance from the source of radiation the exposure would be decreased to $(1/2)^2$, or one-fourth, of the original amount. By increasing the distance from 2 to 20 m, the exposure would be decreased to $(2/20)^2$, or one percent, of the original amount. While the inverse square law can be used as an approximation, it should be recognized that it applies only to a point source in free space where there is no scattering of radiation. In practical applications, the radiation source may not be equivalent to a point source, and surrounding surfaces may reflect some radiation so that free space does not apply. However, in most instances, the approximation is adequate.

Maintaining a safe distance is especially critical for employees who must work near inadequately shielded sources of radiation. This applies to both portable and nonportable source types (Table 10–D).

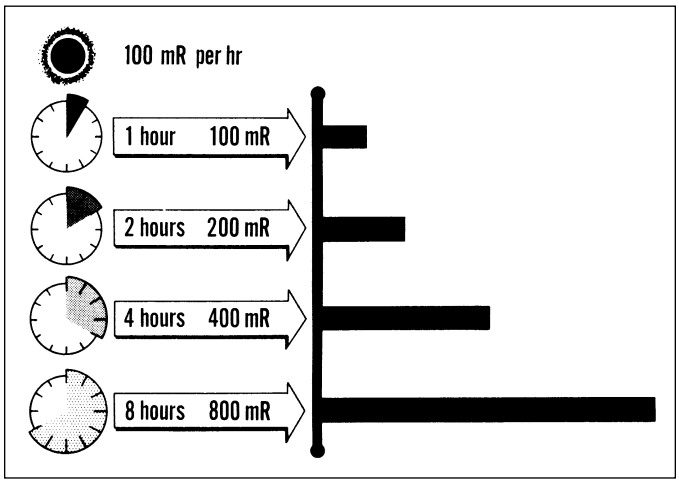


Figure 10–14. The effect of time on radiation exposure is easy to understand. An individual in an area where the radiation level from penetrating x- or gamma-radiations is 100 mrem/h would get 100 mrem in an hour. After two hours, the exposure would be 200 mrem, and so on. (Reprinted from U.S. Nuclear Regulatory Commission, *Living with Radiation—Fundamentals*.)

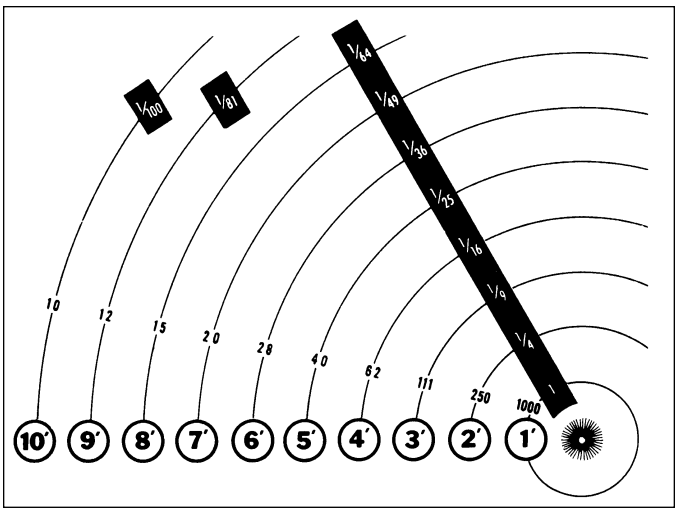


Figure 10–15. The effect of distance on radiation exposure follows the inverse square law—the intensity of radiation falls off by the square of the distance from the source. If we had a point source of radiation giving off 1,000 units of penetrating external radiation at 1 ft (or any other unit of distance), we would receive only one-fourth as much, or $(1/2)^2$, if we double our distance. If we triple our distance, we reduce the dose to one-ninth, or $(1/3)^2$. (Reprinted with permission from *Safe Handling of Radioisotopes in Industrial Radiography,* Picker X-Ray Corp., 1962.)

In such cases, a radiation survey should be made with an appropriate survey meter by a qualified health and safety professional to establish minimum safe distances that workers must abide by.

Work involving penetrating types of radiation should be performed where permanent barriers and shielding protect workers from harmful exposure. However, it is possible that certain operations cannot be performed without some exposure of employees. In these cases, all unnecessary exposure to radiation should be avoided, for example, by barring workers, including technicians, from active areas during exposure time such as during use of x-ray equipment.

A safe distance is the distance nonoperating workers must maintain from the radiation source in order to receive no more exposure than that specified in the NCRP *Radiation Protection Guides,* even if personnel were to remain at that distance continually. The distances specified for a given job do not necessarily remain constant if the radiation source in use is modified.

Hazardous areas indicated by the protection survey must be barricaded or roped off to form a restricted section that cannot be entered by nonoperating workers or bystanders. Large signs bearing the standard radiation symbol with proper wording should be posted (Figure 10–16). Standard colors are magenta on yellow.

Table 10–D. ***Gamma-Emitters and Radiation Levels at Various Distances from the Source***

Isotope	*0.3m*	*0.6m*	*1.2m*	*2.4m*	*3.0m*
Cobalt-60	14.5	3.6	0.9	0.23	0.145
Radium-226	9.0	2.3	0.6	0.14	0.09
Cesium-137	4.2	1.1	0.26	0.07	0.042
Iridium-192	5.9	1.5	0.4	0.09	0.059
Thulium-170	0.027	0.007	0.002	0.0004	0.00027

Note: Distances given in meters; 3.28 ft = 1 m.

(Reprinted form *Safe Handling of Radioisotopes in Industrial Radiography,* Picker X-Ray Corp., 1962.)

Shielding

Shielding is commonly used to protect against radiation from radioactive sources. The more mass that is placed between a source and a person, the less radiation the person will receive (Figure 10–17). For a high-density material such as lead, the barrier thickness required for a given attenuation of x- or gamma-radiation is less than it is for a less dense material such as concrete (Table 10–E).

Shielding from neutrons requires a different approach than does shielding from x- or gamma-radiation. Neutrons transfer energy to, and are stopped most effectively by, light nuclei (hydrogen atoms are the most effective). Therefore, water or other materials rich in hydrogen content are used as shields for neutrons. Carbon atoms such as in graphite are also often applied for neutron shielding.

Shielding can take many forms. These include cladding on radioactive material, containers with heavy walls and cov-

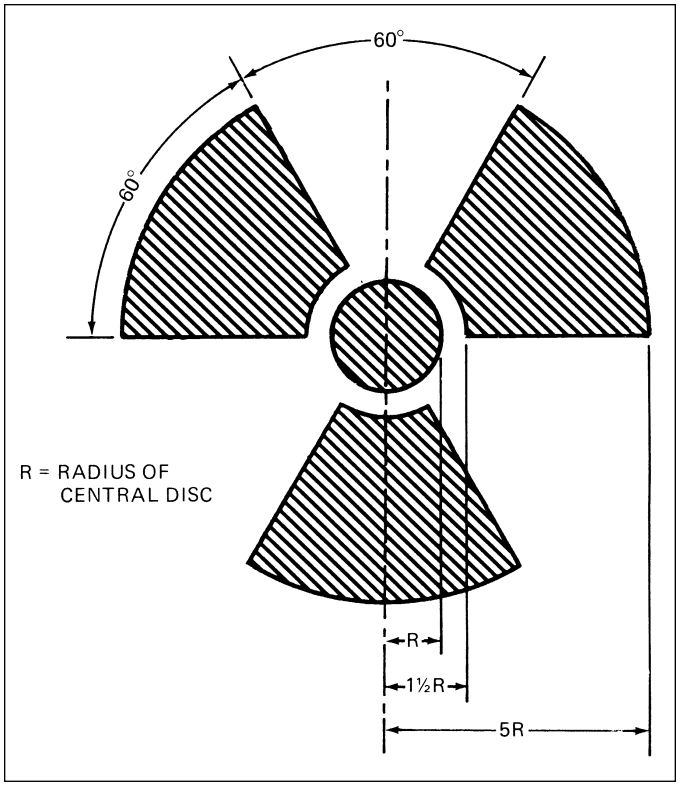


Figure 10–16. Standard symbol for radiation warning signs. (Courtesy American National Standards Institute.)

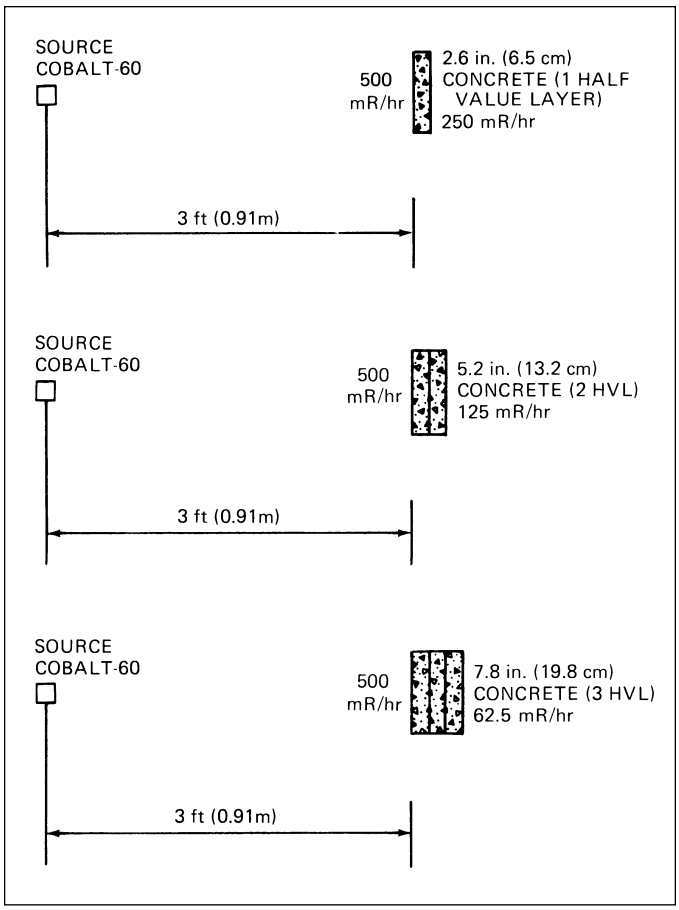


Figure 10–17. Illustration shows attenuation of cobalt-60 gamma-radiation by half-value layers of concrete.

ers for radioactive sources, cells with thick, high-density–concrete walls having viewing windows filled with high-density transparent liquid for remote handling of high-level gamma-emitters, and a deep layer of water for shielding against gamma-radiation from spent nuclear reactor fuel. Shielding calculations are often highly technical and require the services of an expert in this area.

Tables of half-value layers are given in radiation handbooks, and typical values for two radioactive materials, cobalt-60 and cesium-137, are given in Table 10–A.

Table 10–A states that 2.6 in. (6.6 cm) thickness of concrete can reduce the gamma-radiation coming from any cobalt-60 source to a factor of 1/2. If the gamma-emitter is cesium-137, then the half-value layer for concrete becomes 2.1 in. (5.3 cm). The gamma-radiation from cesium-137 is lower in energy (not as many MeVs) than the gamma-radiation from cobalt-60. Figure 10–17 illustrates how additional mass reduces radiation levels. The example used is a cobalt-60 source that gives a meter reading of 0.5 roentgen per hour (5 mGy/hr) at a distance of 3 ft (0.91 m).

A formula used for gamma-emitters is

Equation 3

$$\text{R/hr at 1 ft} = (6)(Ci)(E)(f)$$

This relationship states that the number of roentgens (R) per hour measured at a distance of 1 ft (0.3 m) from a source is approximately equal to six times the curie strength (Ci) of the source times the energy (E) of the gamma-radiation in MeV times the fractional yield (f) of the gamma-radiation per disintegration. It cannot be used for estimating beta-radiation levels.

Given the name of the radioactive source and its quantity (or activity) in curies, the value for its energy in MeVs can be obtained from handbooks. For example, Table 10–B gives the energy of radiation from several radioactive isotopes. The fractional yield (f) of the gamma-radiation per disintegration can be found in the *Handbook of Health Physics and Radiological Health* (see Bibliography).

Two cautions are required for proper application of this formula:

➢ Some radioactive materials such as cobalt-60 emit more than one gamma, each with different energies. The sum of the energy of the total emissions must be used. This information can be found in handbooks.

Table 10–E. ***Approximate Tenth- and Half-Value Thicknesses for Shielding Radiographic Sources***

Radiographic Source	Tenth- and Half-Value Thicknesses (cm)					
	Lead		Iron		Concrete	
	1/10	1/2	1/10	1/2	1/10	1/2
(Cobalt) Co-60	4.11	1.24	7.36	2.21	22.9	6.90
(Radium) Ra-226	4.70	1.42	7.70	2.31	24.4	7.37
(Cesium) Cs-137	2.13	0.64	5.72	1.73	15.7	4.83
(Iridium) Ir-192	1.63	0.48	*	*	15.7	4.83

* = No data.

Notes: This thicknesses for tenth- and half-value layers provide shielding protection from the scattered radiation resulting from deflection of the primary gamma-rays within the shield as well as protection from primary radiation from the source. The tenth-value layers were determined from the reduction factor v shield thickness curves. The tenth-value thicknesses were taken as one-third the thickness of shielding material necessary to give a reduction factor of 1,000. The half-value thickness is equal to the tenth-value thickness divided by 3.32.

1 cm = 0.394 in.

Density of concrete assumed to be 2.35g/cm^3 (147 lb/ft^3).

(Reprinted from the Nuclear Regulatory Commission Publication U-2967.)

➢ Terms must be consistent. If the source activity is given in millicuries or microcuries, it should be converted to curies. If millicuries are used in the source term, then the answer is in milliroentgens.

EXAMPLES/APPLICATIONS:
Example calculations for expected radiation levels are as follows:

Example
What radiation reading would be expected at a distance of 1 ft from an unshielded 100-millicurie cobalt-60 source?

Equation 4

$$\text{R/hr at 1 ft} = (6)(Ci)(E)(f)$$

where Ci = 100 millicuries (0.1 curie)
E = 1.2 MeV + 1.3 MeV (from handbook tables)
f = 1 (from handbook tables)
h = hour
R = Roentgen

Solution
Equation 5
R/h at 1 ft = 6(0.1) (1.2 + 1.3) (1) = 1.5 R/h (15mGy/h)

Example
What radiation reading would be expected at a distance of 1 ft from an unshielded 1-millicurie cesium-137 source?

Solution
Equation 6

$$\text{R/h at 1 ft} = 6(0.001)\ (0.66)\ (0.9) = 0.0036$$

which is 3.6 milliroentgens per hour (36mGy/h) at 1 ft (0.3 m).

The preceding examples illustrate the use of the formula in calculating dose rates and show how the application of the formula can assist in the interpretation of fractional amounts of curies.

The fact that a one-millicurie source of cesium-137 is used does not quantify the exposure problem. However, by calculating the exposure rate of 3.6 milliroentgens per hour at one foot, and then applying the distance rule of decreasing radiation (one divided by the distance squared— the inverse square rule) it becomes apparent that 4 ft (1.2 m) away from the source the radiation level would be $3.6/(4)^2$ = 0.22 mR/h (2.2µGy/h), which is very low.

Table 10–D lists a number of gamma-emitters and their radiation levels measured at various distances from a one-curie source. The numbers were obtained by using the previous formula and then applying the inverse square law for distances of other than one foot.

Knowledge of existing radiation levels at various distances from various radioactive sources facilitates use of control procedures to ensure that cumulative doses do not exceed the maximum permissible dose (MPD).

Example
As a final example of how control calculations can be used, assume that a 0.5-curie cobalt-60 source is involved in a fire. The radiation meters have been damaged and there is reason to believe that the source container is not functioning as an effective shield. Until someone with a good meter can conduct a survey and determine how severe the problem is, at what distance should the area be fenced off?

Solution
First, calculate R/h at 1 ft for a 0.5-curie cobalt-60 source.

Equation 7

$$\text{R/h at 1 ft} = 6(0.5)(2.5)(1) = 7.5 \text{ or } 7{,}500 \text{ milliroentgen per hour at one foot}$$

Second, at a control level of 40 milliroentgens per week (0.4 mSv per week) for a 40-hour week, the dose rate per hour should not exceed 40 mR/40 h or 1.0 mR/h (10mGy/h).

Third, use the inverse square law as follows:

Equation 8

$$x \text{ ft} = \left(\frac{\text{mrem/h at 1 ft}}{1.0 \text{ mrem/h}}\right)^{0.5}$$

$$= \sqrt{\frac{7{,}500 \text{ mrem/h at 1 ft}}{1 \text{ mrem/h at control ft.}}}$$

The distance in feet to place the barricade equals the square root of the quotient (milliroentgen per hour at one foot divided by 1.0 milliroentgen per hour). Thus,

Equation 9

$$x \text{ ft} = \left(\frac{7{,}500}{1.0}\right)^{0.5} = 86.6 \text{ ft}$$

Workers should not be allowed within 86.6 ft (26.2 m) of the source location. The warning signs and rope barrier or other access barrier should be placed not nearer than 86.6 feet from the radiation source. (All examples assume that exposures are occupational to workers with accurately maintained radiation exposure records.)

Calculations can be useful for planning purposes and subsequently actual radiation levels will need to be monitored.

CONTROL PROGRAMS

A radiation health and safety program should establish safe working procedures, detect and measure radiation, make surveys, be concerned with decontamination and disposal, laboratory and other special services, and record keeping.

Ionizing radiation cannot be felt, seen, heard, tasted, or smelled. However, radioactive isotopes can be measured and identified with instruments, and therefore can be adequately controlled.

A basic concept in radiation protection practice is the establishment of a controlled area. Areas where radiation dose rates are excessive can be guarded during exposure times by suitable methods such as the erection of barriers and warning signs (Figure 10–15), stationing of attendants to keep personnel out of restricted localities, and, in extreme cases, complete closing off of the areas. Safe exposure times and safe practices can be established through measurement and control and by learning from past experience.

Work with radiation can and should be so planned and managed that radiation exposures of employees and the general public are kept to a minimum. Controls are needed to prevent the release of radioactive materials that would result in exposures above guide levels.

Potential avenues of exposure to the public are contaminated air or water, waste materials, or employees unknowingly leaving the place of work with contamination on their persons, clothing, or shoes. Use of a hand-and-shoe monitor is shown in Figure 10–18.

Sources of Radiation

One must always consider the amount and kind of radiation sources used in a contemplated operation. Suitable radiation safety operating conditions can then be designed. Special circumstances can greatly affect the safety requirements.

Table 10–F lists a number of radioactive materials according to their toxicity. Table 10–G classifies the laboratory or work area required for radioactive materials of differing toxicity.

Radionuclides are often used because measurements of their radiation can disclose useful information. One example is the employment of radioactive sources to effect quantitative or dimensional control of industrial materials. For example, radionuclides can measure fluid-flow rates or thickness of semifinished or finished products.

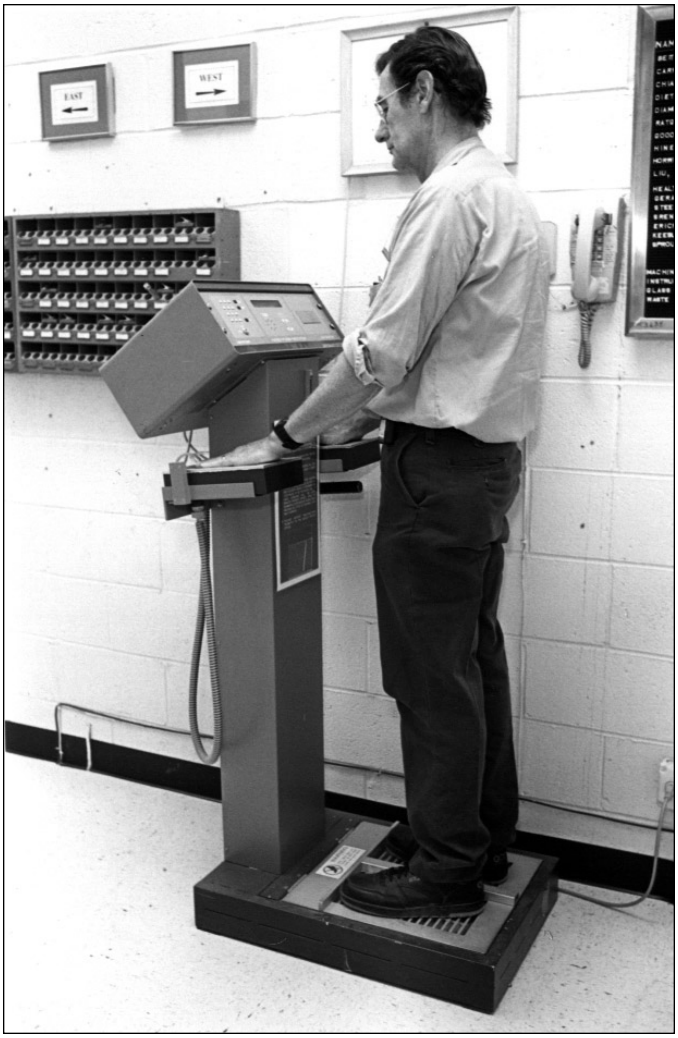


Figure 10–18. Use of a hand-and-shoe monitor for final radiological checkout.

SEALED SOURCES

Sealed sources with widely varying amounts of radioactivity are available. A high-intensity source may require so much

Table 10–F. *Classification of Isotopes According to Relative Radiotoxicity per Unit Activity*

The isotopes in each class are listed in order of increasing atomic number	
CLASS 1 (very high toxicity)	Sr-90 + Y-90, *Pb-210 + Bi-210 (RaD + E), Po-210, At-211, Ra-226 + percent * daughter products, Ac-227, *U-233, Pu-239, *Am-241, Cm-242
CLASS 2 (high toxicity)	Ca-45, *Fe-59, Sr-89, Y-91, Ru-106 + *Rh-106, *I-131, Ba-140 + La-140, Ce-144 + *Pr-144, Sm-151, *Eu-154; *Tm-170, Th-234 + *Pa-234, natural uranium
CLASS 3 moderate toxicity)	*Na-22, *Na-24, P-32, S-35, Cl-36, *K-42, *Sc-46, Sc-47, *Sc-48, *V-48, *Mn-52, *Mn-54, *Mn-56, Fe-55, *Co-58, *Co-60, Ni-59, *Cu-64, *Zn-65, *Ga 72, *As-74, *As-76, *Br-82, *Rb-86, *Zr-95 - *Nb-95, *Mo-99, Tc-98, *Rh 105, Pd-103 - Rh-103, *Ag-105, Ag-11, Cd-109, *Ag-109, *Sn-113, *Te-127, *Te-129, *I-132, Cs-137, *Ba-137, *La-140, Pr-143, Pm-147, *Ho-166, *Lu-177, *Ta-182, *W-181, *Re-183,*Ir-190, *Ir-192, Pt-191, *Pt-193, *Au-198, *Au-199, Tl-200, Tl-202, Tl-204, *Pb-203
CLASS 4 (Slight toxicity)	H-3, *Be-7, C-14, F-18, *Cr-51, Ge-71, *Tl-201

Note: The isotopes in each class are listed in order of increasing atomic number.

*Gamma-emitters.

(Reprinted from *Safe Handling of Radionuclides,* Safety Series No 1, International Atomic Energy Agency, Vienna.)

Table 10–G. ***Laboratory or Work Area Required for Isotopes of Increasing Radiotoxicity***

		Type of Laboratory or Work Area Required		
Radiotoxicity of Isotopes	*Minimum significant quantity*	*Type C Good Chemical Laboratory*	*Type B Radioisotope Laboratory*	*Type A High-Level Laboratory*
Very high	0.1 μCi	10 μCi or less	10 μCi–10 mCi	10 mCi or more
High	1.0 μCi	100 μCi or less	100 μCi–100 mCi	100 mCi or more
Moderate	10 μCi	1 mCi or less	1 mCi–1 Ci	1 Ci or more
Slight	100 μCi	10 mCi or less	10 mCi–10 Ci	10 Ci or more

Procedure	*Modifying factor*
Storage (stock solutions)	X 100
Very simple wet operations	X 10
Normal chemical operations	X 1
Complex wet operations with risk of spills	X 0.1
Simple dry operations	X 0.1
Dry and dusty operations	X 0.01

Note: Modifying factors should be applied to the quantities shown in the last three columns, according to the complexity of the procedures to be followed. Factors are suggested only because due regard must be paid to the circumstances affecting individual cases.
(Reprinted from *Safe Handling of Radionuclides*, Safety Series No. 1, Atomic Energy Agency, Vienna.)

shielding that it is not considered portable. Shielding, control devices, and procedures should be designed by someone experienced in such work. Keeping external exposures to personnel under control can be accomplished with the aid of alarms, interlocks, strict control of access, and thorough monitoring.

Sources of low intensity should only require keeping track of their presence and condition.

Sources of intermediate intensity are more troublesome. They are portable and in some cases require so little shielding that they can easily be moved by hand. Persons operating a portable source must consistently follow the necessary precautions, including the use of dosimeters to measure their own exposure. They must operate the source so that other persons are not accidentally irradiated.

Some sealed sources are subject to breakage and spillage, and even welded seals have been known to fail. The hazard can be severe, and great care should be taken in handling sealed sources. Even if no known accident has occurred, such sources should be tested for leaks by a standardized procedure at scheduled intervals by an experienced technician.

RADIATION-PRODUCING MACHINES

For many years, radiation-producing machines have been in use, and proper operation of x-ray machines has been described in many publications. Remote actuation and shielding are common ways to control personnel exposures. If an accelerator is used, radiation safety personnel with special training or experience are required to ensure proper installation and operation. (See Bibliography, NCRP Report 88.)

Portable x-ray units present many of the same kinds of radiation safety problems as nonportable sources of corresponding intensity. Special problems related to the portability and lack of stationary shields must also be considered.

RADIOISOTOPES

Use of radioisotopes in the laboratory encompasses a wide range of hazards. The degree of hazards depends on the quantities and types of radioisotopes used as well as the kinds of operations to be performed.

Radioisotopes must be considered individually when hazards are being analyzed because their effect on human health varies with the type of radiation emitted, the process or work being conducted, and the safety practices being employed by those conducting the work. No general statements can be made until specific information is gathered and analyzed. Controls and procedures should be established by a health physicist.

Table 10–F groups various radioisotopes according to their relative radiotoxicity per unit activity in accordance with the International Atomic Energy Agency's (IAEA) publication, *Safe Handling of Radionuclides*. The IAEA explains the hazard classification for unsealed radioactive sources as follows:

> *Hazards arising out of the handling of unsealed sources depend on factors such as the types of compounds in which these isotopes appear, the specific activity, the volatility, the complexity of the procedures involved, and of the relative doses of radiation to the critical organs and tissues, if an accident should occur that gives rise to skin penetration, inhalation, or ingestion.*

Broad classifications for the radiotoxicity of various isotopes and their significant amounts are given in Tables 10–F and 10–G.

Spent fuel elements from a nuclear power reactor can contain on the order of a million curies, depending on the length of time they have been irradiated in the reactor and the interval of time between their removal from the reactor and measurement of their radioactivity. Shielding is required for handling, storage, and shipment of spent fuel materials and other high-level gamma-radiation sources. The use of manipulators, shielding cells, and shielding windows for remote work is shown in Figures 10–19 and 10–20. This illustrates confinement and shielding for high-level gamma-radioactivity. The photographs show the use of an in-cell remote camera and external video screen in Figure 10–19 and the remote use of strippable decontamination paint in Figure 10–20.

RADIOACTIVE METALS

Radioactive metals vary greatly in degree of hazard. Some have such low radiation rates that they can safely be held in the hand (if they are solids that are not flaking or dusting). A piece of normal uranium or an alloy of this material, for example, can be safely handled without personal protection for a few hours per week. It is good practice, nevertheless, to wear gloves when handling such materials, because metals (like uranium) can oxidize and develop a flaky surface. Use of metal cladding or a paint-type surface coating may be necessary to avoid loose contamination. Respiratory protection may also be needed.

Certain radioactive metals have such high surface dose rates that they must be handled only with remote control devices. If a solid radioactive metal has a loose contaminating layer of radioactivity on its surface, it must be handled in a ventilated enclosure equipped with a high-efficiency exhaust filter. In each case, the radiation level of the particular material and its composition must be known before safe handling practices can be determined.

Instrument measurement of the dose rate from the material help determine the control measures needed. Exposure time, distance, and shielding are the basic control measures. Confinement and other means to avoid intake of radioactive material constitute other important control measures. Review of processes and handling history, visual inspections, and smear and air sampling are useful when determining the probability of contamination incidents and the necessary control measures.

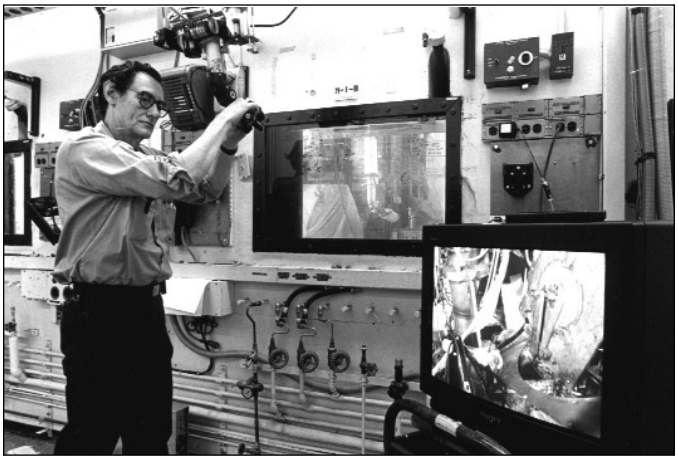


Figure 10–19. Use of a remote camera and external video screen for viewing areas in a hot cell.

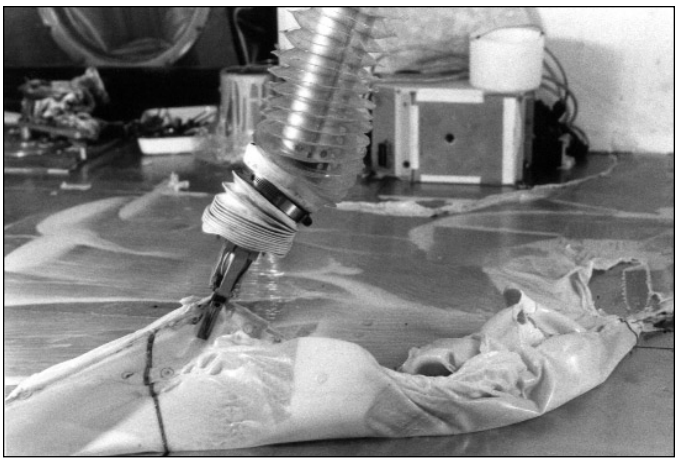


Figure 10–20. Remote removal of strippable decontamination paint in a hot cell.

Uranium metal will burn under certain conditions and, along with some alloys used in chemical operations, poses a chemical explosion hazard. Casting of uranium metal must be done in a vacuum. It is necessary to use an inert gas, rather than air, to break the vacuum. Wastes and scraps must be carefully handled from the time they are generated until they are ultimately disposed of, not only for reasons of safety, but also because of their monetary value.

Cutting of uranium with abrasive cutoff wheels requires special local exhaust ventilation. Because chips, turnings, and finely divided uranium burn spontaneously under some conditions, it is advisable to convert uranium into oxide daily, as the scrap is accumulated. Uranium-contaminated waste requires packaging that meets U.S. Department of Transportation and disposal site criteria.

CRITICALITY

Criticality is the fissioning, or breaking apart, of nuclei, with emission of neutrons at a rate faster than neutrons are absorbed or lost from the system. It results in a highly hazardous instantaneous burst of neutrons with associated high-level gamma-radiation. Whenever the presence of fissionable radioactive materials such as uranium-235 and plutonium-239 necessitates criticality controls, an expert in this area of radiation safety must be involved.

A number of fatalities have resulted from criticality incidents, and even personnel at considerable distances from the source can receive severe radiation exposure. Stringent controls over amounts and movement of fissionable materials are necessary. Immediate local sensing of a critical incident and audible alarms to trigger quick evacuation are other precautions employed to protect against this hazard.

PLUTONIUM

Plutonium is a highly hazardous alpha-emitter that must be handled under rigidly controlled conditions. Enclosures, some of which are called glove boxes or dry boxes (Figure 10–21), must be carefully designed and are relatively expensive. Glove boxes must be maintained at a negative pressure, and may necessitate an inert atmosphere such as argon or nitrogen to avoid fires. Plutonium is pyrophoric under certain conditions. Plutonium-239 is fissionable and presents a criticality control problem when sufficient amounts are present (>300 grams).

Glove-box exhaust gas is usually filtered by two or more high-efficiency particulate air (HEPA) filters in series. Emergency power for exhaust ventilation and alarms for loss of negative pressure in the boxes are system safety features.

Because glove-box gloves can develop pinholes, cracks, tears, or punctures, workers wear another pair of protective gloves when using them. Workers should monitor their gloved hands periodically and monitor and remove protective clothing when leaving the work area.

Operational Factors

Ascertain the required level of radiation protection and evaluate the problems that might arise by analyzing the radiation work in terms of the following factors:

- ➢ Area involved (in square feet or meters), and number of rooms and buildings.
- ➢ Number of employees exposed to radiation and in what locations.
- ➢ Chemical and physical states of the radioactive material and the nature of its use.
- ➢ Incidents that might occur and their possible locations.
- ➢ Nonradiation hazards involved.
- ➢ Nature of the probable radiation exposure or release of radioactive material:

  Controlled, or supervised, release (as in a disposal operation)

  Accidental release or exposure that cannot be sensed by radiation-detection instruments

  Violent release of dust, droplets, gases, or vapors through fire, increase in temperature, or explosion

  Spread of contamination as the result of its adherence to other material or through spillage
- ➢ Inherent danger of the material because of its internal or external effect on humans. This danger depends on the isotopic and chemical forms of the material (Bibliography, NCRP Report 22).
- ➢ Probability of detection of hazardous situation by routine surveys or monitoring.
- ➢ Knowledge of current conditions is essential to determine the acceptability of the risks involved.
- ➢ Possible effects of accidents on operations, such as interruption of production, loss of occupancy of space, loss of equipment, and cost of cleanup.

Employee Exposure Potential

The industrial accidents that can produce radioactive contamination are usually no more difficult to prevent than the more common types of industrial accidents, but there is an added, compelling reason to control them—the danger of intake of radioactive materials by personnel.

Monitors for detecting radioactive contamination of personnel are shown in Figures 10–13 and 10–18. It is impor-

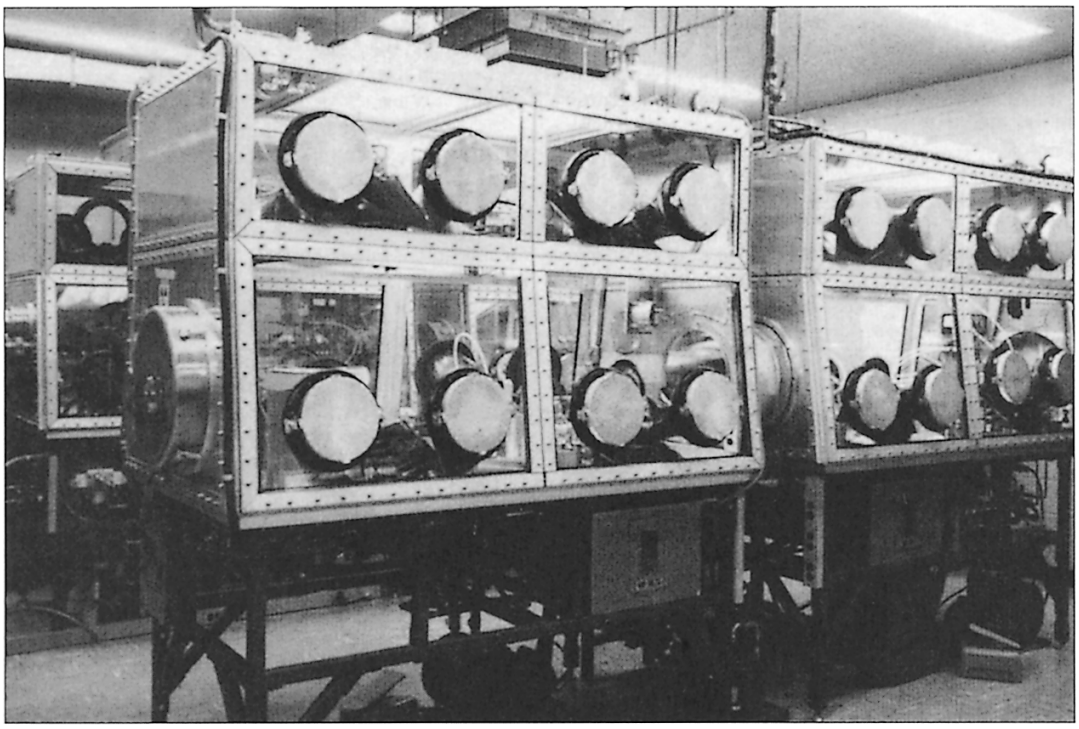


Figure 10–21. A glove box type of hood permits rigid control of conditions when radioactive metals are worked. (Courtesy Argonne National Laboratory.)

tant that the appropriate monitoring instruments be available and properly maintained and calibrated.

EXTERNAL HAZARDS

Under ordinary operating conditions, and barring accidents, the level of exposure to external radiation can be determined through use of continuously monitoring instruments or dosimeters, or from previous measurements of radiation fields for identical operations. The problem is then reduced to limiting the rate of exposure or the length of exposure time. Instrument measurement of the exposure indicates what advantage can be obtained by installing additional shielding or by having personnel work farther from the source of radiation.

Under emergency conditions with high-exposure levels, it is advisable to rotate personnel so as to prevent exposure of any one individual above guide levels. Emergency exposure levels for extreme conditions have been published in NCRP Report No. 116, *Limitation of Exposure to Ionizing Radiation*. These are essentially once-in-a-lifetime allowances for handling an extremely serious situation.

Occasionally, an unexpectedly high reading appears on a personal dosimeter. While the reading may be invalid for any one of a number of reasons, an investigation should be conducted to determine whether or not the reading was valid and what should be done to prevent recurrences.

INTERNAL HAZARDS

Inhalation is the most frequent route of entry of radioactive material into the body. Routine air sampling can detect the concentration, and a constant air-monitoring system can be designed to sound an alarm if hazardous levels are detected. Also, employees are likely to recognize conditions that in the past have resulted in exposure, and can act promptly to minimize exposure.

In the event that a spill of radioactive material is detected by immediate recognition, hand and foot monitoring, or through air or room surface monitoring, prompt action is essential. If there is a potential inhalation hazard, personnel should evacuate to the nearest safe location. Further movement of workers should be restricted until a monitoring survey can be done to determine the extent of radioactive contamination. Quick arrangements should be made to restrict exit from and entry into the building, wing, or laboratory until there is a determination that radioactivity has not and will not be tracked or carried out to other areas. Corridors should be roped off or posted to control movement until monitoring of personnel, surface, and air shows that contamination is controlled.

It is important to isolate and clean up a spill as soon as possible. Personnel who conduct the monitoring and cleanup should wear appropriate protective equipment and clothing. The incident can be resolved as soon as there is assurance that the potential hazards have been controlled.

A less common route by which radioactive material enters the body is through broken skin, and in rare cases this can be more serious than entry through the lungs. When radioactive materials gain entry through a minute cut or abrasion, they enter the bloodstream and are then dispersed throughout the body. The result can be serious if there is a high concentration of the radioisotope at the skin break. If the workers have been appropriately educated, the injured person will be aware of the possible danger and can request a radiation survey of the wound area.

By and large, absorption through intact skin is not a significant route of entry. Tritiated water vapor is one of the exceptions; it is absorbed rapidly through unbroken skin. It is important to scrub up immediately when significant skin contamination occurs. This minimizes the possibility of entry through inhalation, ingestion, or a subsequent skin break and prevents the spread of the radioactive material.

Analysis of the radionuclide content of body fluids and excreta and whole-body counting are important for after-the-fact detection of intake of radioactivity. When the presence of radionuclides within the body is detected or an accidental intake of radionuclides becomes known, steps should be taken to determine the cause and prevent recurrence. This serves as a backup to environmental monitoring.

Records

Some diseases that are caused by exposure to radiation or radioactive materials occur after many years of exposure. Retention of suitable records relating to exposures and working conditions is desirable and is usually required.

SUMMARY

It is impossible to discuss all of the important aspects of radiation safety in a fundamentals manual such as this. Nevertheless, health and safety professionals will have a good background for further study and assistance in radiation safety if they do the following:

- ➢ Recognize that ionizing radiation control requires the expertise of qualified health physics personnel.
- ➢ Treat radiation and radioactive materials with respect because of the recognized potential hazards.
- ➢ Recognize the two distinct types of exposure hazards involved: external and internal.
- ➢ Learn about the various types of ionizing radiation.
- ➢ Know that calibrated monitoring instruments appropriate for the specific type of ionizing radiation must be used for measurements.
- ➢ Recognize the importance of basic exposure control measures including time, distance, and shielding.
- ➢ Know that control guidelines and exposure limits must be followed.

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Chapter 11

Nonionizing Radiation

by Gordon Miller, CIH
revised by Michael Yost, PhD

Radar was one of the scientific wonders to emerge from World War II, but there is controversy over whether it is safe. Microwaves are finding more and more uses as portable communications change from luxury to necessity. There is a radar in a box in most kitchens and no food products supplier can ignore the need to package food so it is microwavable. Lasers were a scientific wonder of the 1960s, but now laser CDs have displaced phonograph disks and most offices have at least one laser printer. One hallmark of technological change is the increasing use of the electromagnetic spectrum, and it is certain that new uses of electromagnetic energy will be found after this edition is published. Perhaps the scientific controversy regarding the safety of power line fields will be at least partially resolved before this chapter is revised for the next edition. This chapter presents the basic principles of electromagnetic fields and radiation and how to protect people from the hazards associated with this energy.

ELECTRIC AND MAGNETIC FIELDS

Electric Fields

Atoms are divided into a central part, the *nucleus,* and *electrons* that orbit around the nucleus. The *protons* in the nucleus carry what is arbitrarily called a *positive charge* and the *electrons* orbiting about the nucleus carry what is called a *negative charge*. Negative charges attract positive charges, negative charges repel other negative charges, and positive charges repel other positive charges. These parts are able to exert a force on other distant objects; they create a force field. This field is an electric field, often visualized as lines of force that originate at a positively charged object and end at a negatively charged object, as shown in Figure 11–1. The charge state (positive or negative) is the *polarity*. The force exerted by a charged object on another charged object at a distance depends on the amount of charge in the objects, the

polarity of the charges in the objects, and the distance between them. *Force* is directly proportional to the amount of charge and decreases as the distance between charged objects increases according to an inverse square relationship. If some level of *electric force* exists at a given distance, the electric force is one quarter as great at twice the distance, one ninth as much at three times the distance, and so on. Any charged object creates an electric field whether it is stationary or in motion.

The electric force is very powerful. Opposite charges attract and meet to cancel each other out. For example, the protons in the nuclei of atoms attract an identical number of electrons so the atom is neutral. Electrical imbalances are rare, so a much weaker force created by all matter—gravity—dominates. An object carrying an electric charge is an *ion.* An *ion* can be an atom carrying too few or too many electrons or a bigger object, such as a dust particle, with a deficit or surplus of electrons.

Magnetic Fields

A *moving* electric charge creates yet another field: *magnetism.* Imagine electric charges are moving in some direction, such as through a wire. The amount of charge flowing past a given point is the current. *Magnetic fields* exist in a direction perpendicular to the direction of the current flow. The orientation of the field is such that the north-seeking end of a compass needle points as shown in Figure 11–2a. Magnetic field polarities are given as north and south, and magnetic fields are usually visualized as lines of force that start at the north pole of a magnet and come back around, land on the south pole of the magnet, and complete a circuit by going through the body of the magnet until they reemerge at the north pole. Thus, magnetic fields don't radiate out into space as electric field lines do; they return to the other pole, as shown in Figure 11–2b. The north pole of a magnet points to the north pole of the Earth.

A magnetic field exerts a force on moving electrically charged particles in a direction perpendicular to the field. The force is proportional to the amount of moving charge (the current flow) and the distance between the system carrying that current and a charged object.

When a magnetic field changes, in time it causes nonmoving charges to move or induces a current flow in objects that conduct electricity, including the human body. The human body is mostly made of salt water, a good conductor filled with ions. Thus, a person in a changing magnetic field experiences current flow in loops oriented perpendicular to the direction of the magnetic field, as shown in Figure 11–3.

People are usually unaware of this current flow, but it is always happening because they are immersed in magnetic fields that change with time (time-varying fields) arising from the transmission and use of alternating current (AC) electricity. The polarity and strength of the current keeps alternating between positive and negative, so it is called alternating cur-

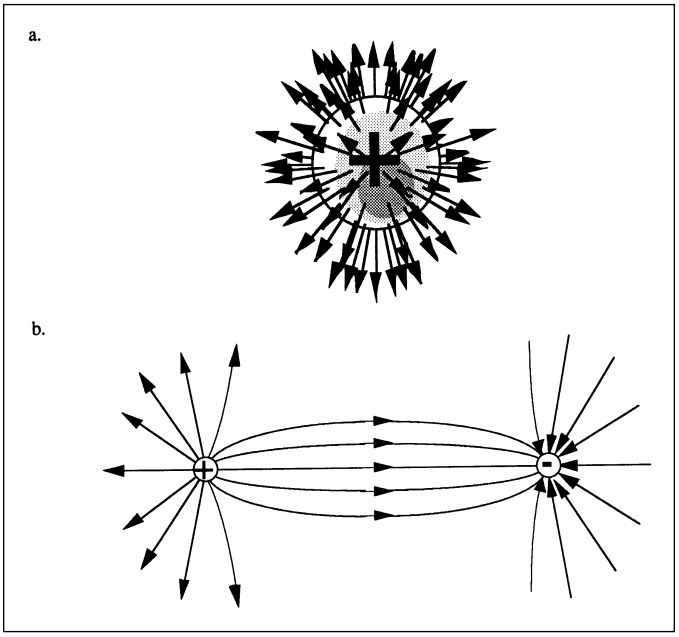


Figure 11–1. Depictions of an electric field. a. Electric field lines originating at a positively charged object and extending out equally in all directions. b. Electric field lines leaving a positively charged object and landing on a negatively charged object. If the objects had the same charge, the field lines would push away from each other.

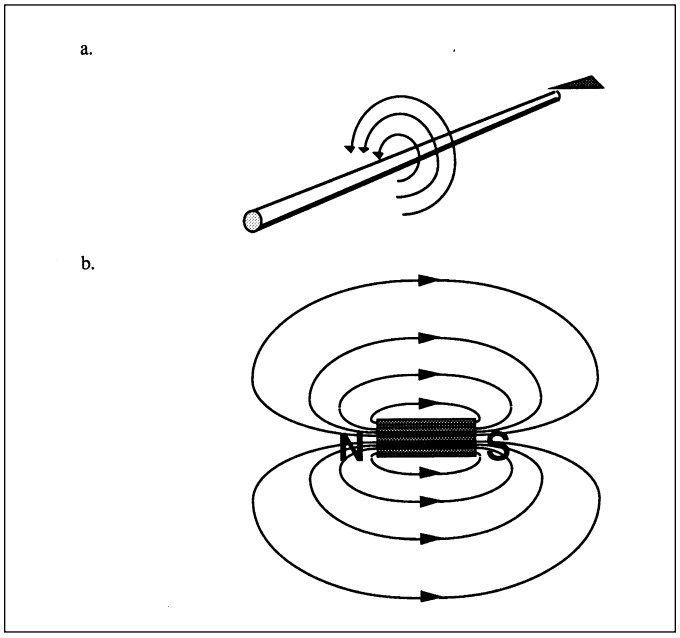


Figure 11–2. Depictions of a magnetic field. a. Magnetic field created by current flow. In this figure, current flows from negative to positive, as shown by the arrow pointing right at the upper end of the wire. The north-pointing needle of a compass will point in the direction of the smaller arrows around the wire. b. Fields around a common bar magnet. Fields form loops that are assumed to start at the north pole, come around to land at the south pole, and move through the magnet. The current flow that creates the field of a permanent magnet is the movement of electrons around atoms.

rent. In the United States and Canada, polarity changes occur 60 times a second (50 times a second elsewhere).

The history of AC power is worth describing because it underlies concerns about power line fields and introduces the basic law of electrical engineering: Ohm's law. Resistance describes the proportionality between the current flow in a conductor, and the potential difference (voltage) across the conductor. Electric current flows from one pole of a source to the other pole, through the source, and back out again for further rounds in the pathway or circuit. The current is measured in units of amperes (A, amps). A useful mechanical analogy is that of the closed-circuit water pump in an aquarium. The pump requires a source of energy to give the water pressure to keep moving because there is resistance to flow in the system. Electrical circuits also have resistance to flow. The unit of electrical resistance (R) is the ohm (Ω) and the unit of pressure or potential that keeps the current flowing is the volt (V). The power (P) is the product of voltage times current, in units of watts. According to Ohm's law, volts equals amps times ohms ($V = I \times R$).

The power loss dissipated in an electrical circuit due to resistance is proportional to the square of the current. Electrical engineers in the early twentieth century faced a problem figuring out how to transmit electric power to distant points. The answer is to keep changing the polarity of the current and use the resulting changes in magnetic fields to induce another current to flow. The device that does this is the transformer, which swaps current for voltage and vice versa. A utility generates current at a voltage of, say, 20,000 V at a power plant, and sends the current to a transformer, which steps up the voltage to create a much smaller current that is transmitted over large distances with low resistance losses. The transmitted current then passes through a sequence of other transformers that step down the voltage in exchange for higher currents and is finally distributed to users at a modest 115 volt potential, as shown in Figure 11–4. Thus electric power is transmitted as a high voltage at a low current, and distributed to customers at a relatively low voltage but larger current. Transmission line voltages range from 69,000 V up to 765,000 V, and the intermediate distribution voltages created by the step-down transformers range from 4,000 to 35,000 V. AC current makes long-distance electrical power systems practical; otherwise, resistance losses would become intolerable.

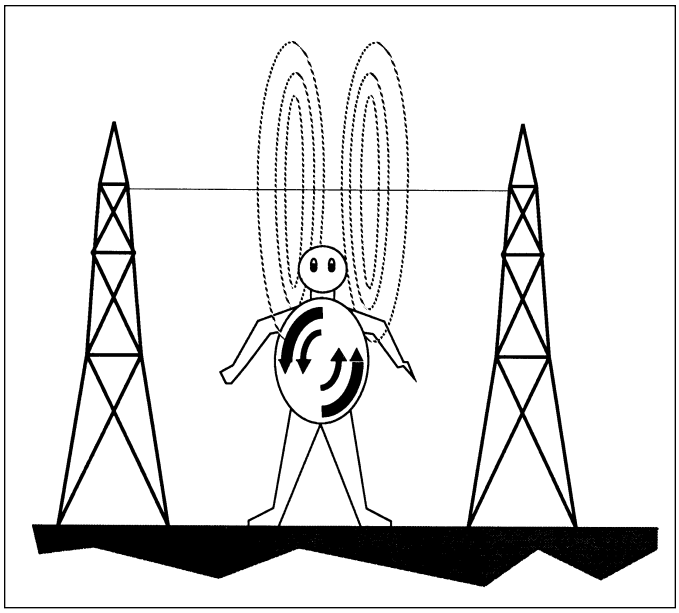


Figure 11–3. Interaction of an AC magnetic field with a person. The field will induce a flow of current at a right angle to the direction of the field. The field radiates out from the line overhead, as shown by dotted lines, but changes direction as the line current changes polarity. The current induced in the body also changes direction. The magnitude of the current is proportional to the radius of the loop it is traveling in, so magnetic fields would be of greatest concern in big organs that are electrically active, such as the brain and heart. (Adapted from Nair, Morgan, and Florig, 1989.)

ELECTROMAGNETIC RADIATION

So far, we have discussed electric and magnetic fields as single entities. There is a common phenomenon where the two exist together: *electromagnetic radiation.*

Electric and magnetic fields change polarities as the fields pass by any given location in space, as shown in Figure 11–5. The number of times the fields change polarity and return to the beginning polarity in a given time is the frequency. The frequency (ν) is usually specified in full cycles of polarity reversals and returns that occur in one second. If the electric field is zero at a given moment and starts climbing to a peak positive value, it will peak, fall back through zero, reach a maximum negative value, and climb back to zero. This is a full cycle. If this happened once in a second, then the frequency would be one cycle per second. If it happens one thousand times a second, then the frequency is one thousand cycles per second. One cycle per second is also called 1 hertz (Hz), after Heinrich Hertz, who discovered radio waves. One cycle per second equals 1 Hz, 1,000 cycles per second equals 1,000 Hz or, using proper metric prefixes, 1 kilohertz (kHz). See Table 11–A for a list of metric prefixes.

Not only do the fields change polarity and strength, but they are rigidly bound together. If the electric field is pointing in some direction, then the magnetic field must move in a direction perpendicular to the electric field, and the wave must travel in yet another direction perpendicular to the other two, as shown in Figure 11–5. Note how the shape of the fields is similar to that of waves on the ocean. They can be drawn by plotting the trigonometric sine or cosine functions and are often called sine waves.

In air and a vacuum, the speed of electromagnetic radiation is 299,792,458 m/s, or about 186,000 mi/s. The speed of light is often rounded off to 300,000,000 m/s. An important way of expressing frequency is the distance the wave travels through one cycle, or the wavelength (λ). The amount of time elapsed

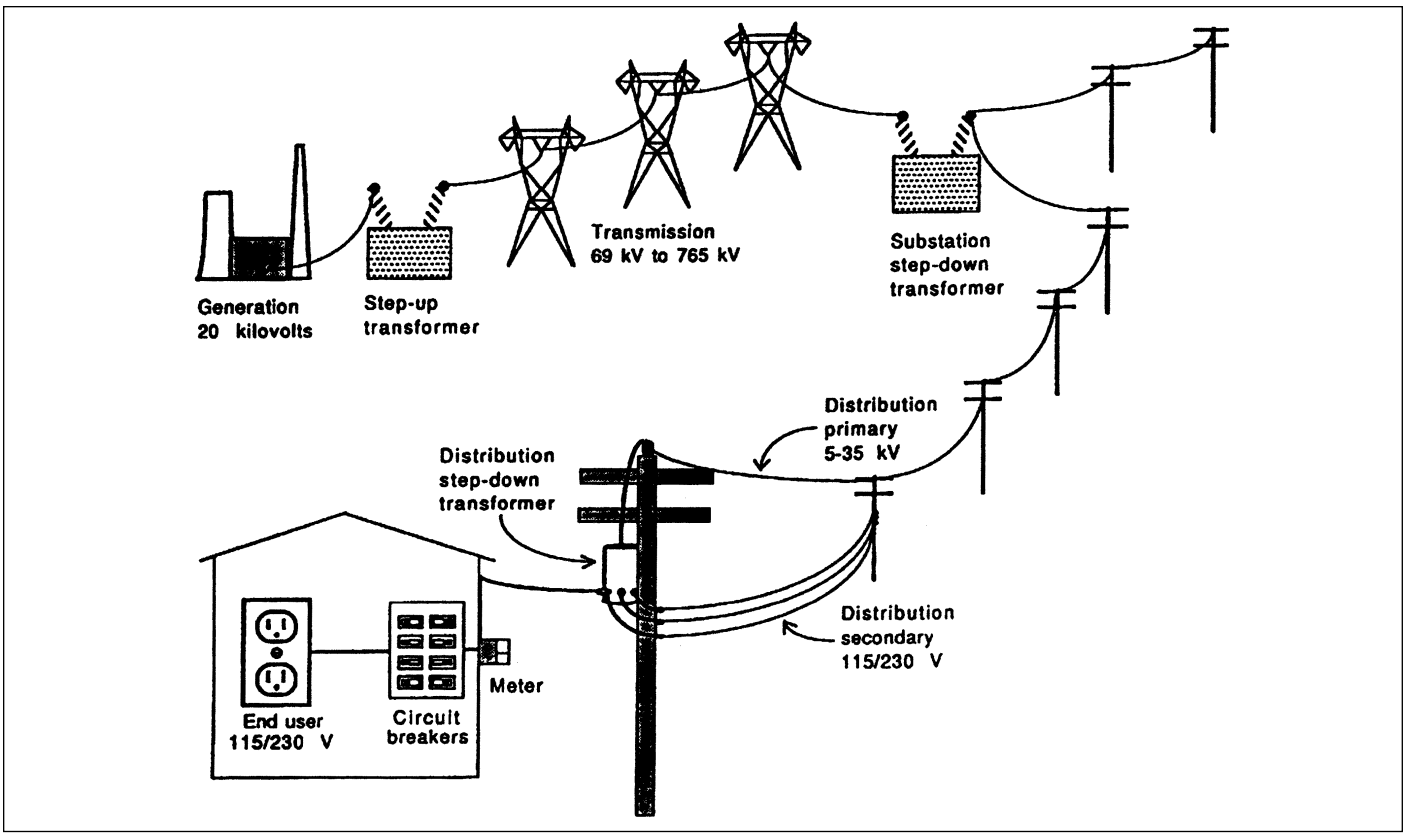


Figure 11–4. Electrical transmission and distribution. Transformers are used at several points, first to step up the voltage and reduce the current so the electricity can be transmitted over large distances with minimal resistance losses, then stepped down to lower voltages at higher current levels before final distribution. Transmission lines are designed to operate with little variation in current, but distribution systems are designed to take broad ranges of current flows. The voltages are fixed at each step and currents vary. (From Nair, Morgan, and Florig, 1989.)

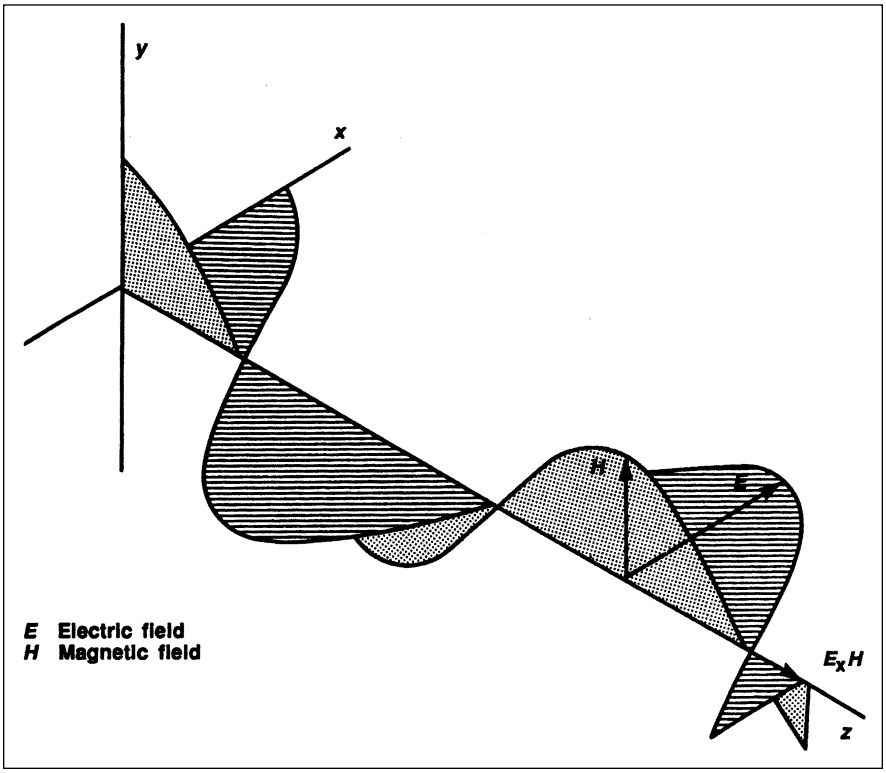


Figure 11–5. The components of electromagnetic radiation. Note that the electric field (E) is oriented in one direction (shown by line-filled curves) whereas the magnetic field (H) (shown by dot-filled curves) is perpendicular to the electric field and the direction of travel is perpendicular to the other two. The number of times that the fields change from a given strength and polarity to the opposite polarity and back to the starting strength and polarity in a second is the frequency. Polarization (not to be confused with polarity or charge state) is the direction of the electric field in relation to the surface of the earth. If the earth were below this page, then this wave would be horizontally polarized. If the electric field were turned 90 degrees (vibrating perpendicularly to the earth's surface), then it would be vertically polarized. The electric field can be caused to change direction constantly; it is circularly polarized if it points in all directions equally, or elliptically polarized if it points more in one direction than another.

Table 11–A. ***Metric Prefixes***

Prefix	*Abbreviation*	*Definition*	*Scientific Notation*	*Common Uses in Nonionizing Radiation*
Atto	a	pentillionth	10^{-18}	—
Femto	f	quadrillionth	10^{-15}	—
Pico	p	trillionth	10^{-12}	Picometer (ionizing radiation wavelengths)
Nano	n	billionth	10^{-9}	Nanometer (UV, visible, and IR-A wavelengths)
Micro	μ	millionth	10^{-6}	Micrometer (IR-B, IR-C wavelengths), microjoule (energy level), microwatt (power level)
Milli	m	thousandth	10^{-3}	Millimeter (microwave or IR-C wavelength), milliwatt (power level)
Centi	c	hundredth	10^{-2}	Centimeter (microwave wavelength)
Kilo	k	thousand	10^{3}	Kilohertz (radiofrequencies), kilometers (wavelengths of radiofrequency and extremely low-frequency radiation), kilowatt (power level)
Mega	M	million	10^{6}	Megahertz (higher microwave frequencies), megawatt (power level), megajoule (energy level)
Giga	G	billion	10^{9}	Gigahertz (higher microwave frequencies), gigawatt (power level)
Tera	T	trillion	10^{12}	Terahertz (IR and visible frequencies)
Peta	P	quadrillion	10^{15}	Petahertz (UV frequencies)
Exa	E	pentillion	10^{18}	Exahertz (ionizing radiation frequency)

during one cycle is called the period, which is calculated by dividing 1 by the frequency, in Hz. The frequency times the wavelength must equal the speed of light, so as frequency increases, wavelength decreases. Wavelength can be calculated by dividing the speed of light, 300,000,000 m/s, by the frequency. Thus, radiation with a frequency of 300,000,000 Hz has a wavelength of 1 m; 60 Hz radiation, if encountered, would have a wavelength of 5,000,000 m (about 3,100 mi).

Electromagnetic Spectrum

The electromagnetic spectrum is summarized in Table 11–B. Note the immense variation in frequencies. A gamma-ray might have a frequency of about 3,000,000,000,000,000,000,000 Hz (300 EHz, wavelength about 0.1 pm), a helium-neon laser pointer has a frequency of about 474,400,000,000,000 Hz (about 474 THz, wavelength 0.632 μm), a microwave oven has a frequency of 2,450,000,000 Hz (2.45 GHz, wavelength 12.2 cm), a well-known New York AM radio station broadcasts at 710,000 Hz (wave length 422 m), and the U.S. Navy's submarine communications system operates at 76 Hz (wavelength about 3,945 km). This is an immense span of frequencies. Frequency is extremely important because the energy of a parcel of electromagnetic radiation, or photon, is directly proportional to its frequency. The electromagnetic spectrum is divided into four parts in this chapter: Subradiofrequency ranges from 0 to 3 kHz, radiofrequency/microwave (RF/ MW) ranges from 3 kHz to 300 GHz, optical radiation ranges from 300 GHz to 3×10^{15} Hz, and ionizing radiation exists at higher frequencies. This chapter covers all of the electromagnetic spectrum except ionizing radiation, which is covered in Chapter 10.

The strength of the magnetic field and the strength of the electric field are related to one another. The ratio of the two is set, in accordance with Ohm's law, by the resistance of the medium in which the radiation is traveling. In air and a vacuum, the resistance is 377 ohms.

The two fields together transmit power through an area of space that can be expressed in watts of power passing through an area of space or striking a given surface area. It is customary to adjust the units to milliwatts of power per cm^2 of area. Radiofrequency and microwave specialists call this power *density;* laser and optical specialists call it *irradiance*. These different terms have the same units and same meaning.

Because power losses are proportional to current, today we use AC electricity. This results from the second basic relationship of electrical engineering: Power (P), in watts, equals current (I), in amps, times resistance (R), in ohms. Recall Ohm's law, which states that volts equals amps times ohms. Combining these two relationships gives the relationship watts equals amps times amps times ohms, or $P = I^2 \times R$. Given that the resistance of air and space is 377 Ω, the relationships given in Table 11–C are widely used by people who do field surveys of radiofrequency and microwave radiation.

WHEN ARE FIELDS IMPORTANT AND WHEN IS RADIATION IMPORTANT?

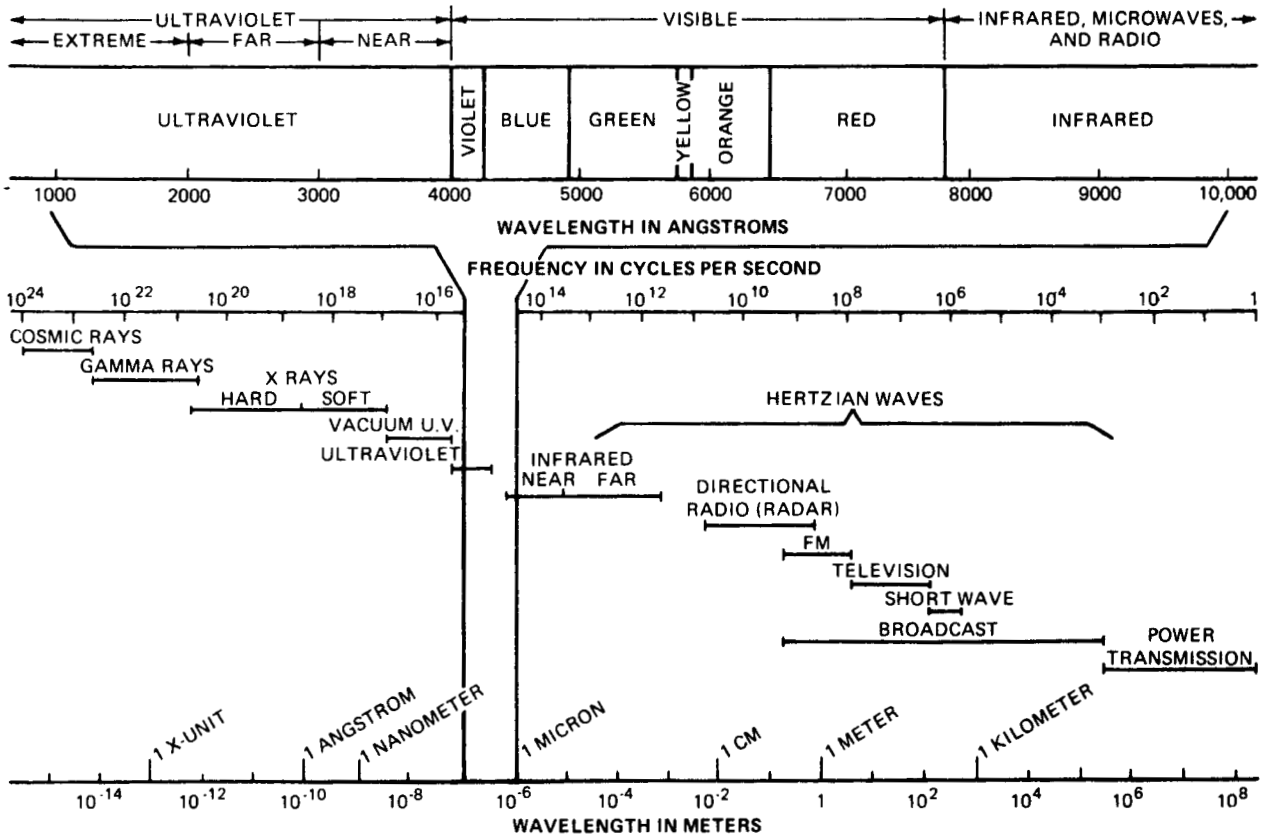
This question is important in the radiofrequency and microwave portion of the spectrum for two reasons:

- ➢ The strengths of the fields in radiation are rigidly related to each other so only one field must be measured (usually the electric field). Both the electric and magnetic field must be measured where radiation does not exist.
- ➢ Radiation obeys the inverse square law unless the source happens to be a laser, so a field strength measurement at one location can be used to calculate field strengths at other distances in the same direction from the source.

Table 11–B. *Two Views of the Electromagnetic Spectrum*

Frequency (Hz)		*Name*	*Wavelength (m)*	*1 (other units)*	*Photon Energy (eV)*	*Type*
3×10^{21}	Gamma rays		10^{-13}		10^{7}	
3×10^{20}		"Hard" x rays	10^{-12}		10^{6}	
3×10^{19}			10^{-11}		10^{5}	Ionizing
3×10^{18}	x rays		10^{-10}	1 Ångstrom	10^{4}	
3×10^{17}			10^{-9}	1 nanometer	1,000	
3×10^{16}		"Soft" x rays	10^{-8}		100	
3×10^{15}		Ultraviolet	10^{-7}		10	
3×10^{14}		Visible (400–760 nm)*	10^{-6}	1 μm	1	
3×10^{13}	Optical	Infrared	10^{-5}		10^{-1}	
3×10^{12}			10^{-4}		10^{-2}	
3×10^{11}		Millimetric microwaves	10^{-3}	1 mm	10^{-3}	
3×10^{10}			10^{-2}		10^{-4}	
3×10^{9}		Microwaves	10^{-1}		10^{-5}	
3×10^{8}	Radiofrequency		1	1 m	10^{-6}	Nonionizing
3×10^{7}			10		10^{-7}	
3×10^{6}			10^{2}		10^{-8}	
3×10^{5}			10^{3}		10^{-9}	
3×10^{4}			10^{4}		10^{-10}	
3,000			10^{5}		10^{-11}	
300	Subradiofrequency ELF		10^{6}		10^{-12}	
30			10^{7}		10^{-13}	
0	DC		—		0	DC

* LIA/ANSI Z136.1-1993 lists the range of visible radiation as 400–700 nm. The eye can perceive longer-wave radiation, but the visual response to it is poor.



The electromagnetic spectrum, encompassing the ionizing radiations and the nonionizing radiations (expanded portion and right). Top portion expands spectrum between 10^{-7} and 10^{-8} m. Note: cycles per second (cps) = hertz (Hz).

Table 11–C. ***Relationships Between Electric Field Strength, Magnetic Field Strength, and Power Density (Irradiance) for Electromagnetic Radiation***

$S_m = E^2/3{,}770$
$S_m = 37.7\ H^2$
$E^2 = 3{,}770\ S_m$
$E = (3{,}770\ S_m)^{1/2}$
$H^2 = S_m/37.7$
$H = (S_m/37.7)^{1/2}$
S_m = Power density in units of mW/cm
E^2 = Electric field strength^2 (V^2/m^2)
E = Electric field strength (V/m)
H^2 = Magnetic field strength^2 (A^2/m^2)
H = Magnetic field strength (A/m)

Separate fields are commonly found at lower frequencies (longer wavelengths). Radiation is commonly found at higher frequencies (shorter wavelengths). As a rule, separate fields are found within one to a few wavelengths of a source. Light has wavelengths ranging between 400 and 760 nm, so light is always found as radiation. A 60-Hz wave has a wavelength of 3,100 miles, so it follows that fields, rather than radiation, are found around power lines. Electrical engineers refer to separate fields as near fields (because they are found close to sources) and to places where radiation is found as far fields. Near fields are divided into *reactive* near fields, which are electric fields created by the voltages and magnetic fields created by current flows in the source, and *radiating* near fields, where electric and magnetic fields combine to form radiation that travels away from the source. The relationship between electric and magnetic field strengths in both near fields is not rigid, so both fields must be measured separately. Electrical engineers have formulas and rules for calculating the distance from specific antennas where far fields exist. It is customarily assumed that separate fields exist when the wavelength is more than about 1 m (frequency of 300 MHz) and that radiation exists at shorter wavelengths or higher frequencies. As a result, *separate electric and magnetic field surveys are needed for frequencies of 300 MHz and less.*

Parts of an Electromagnetic Device

Any electromagnetic device, whether it is a microwave antenna, junkyard magnet, or laser, can be visualized as having three parts: a source, a transmission path, and a receiver. A laser scanner in a CD player has a laser embedded in the device, optics to transmit the energy to the disk, and a sensor to receive the reflected energy. A 27.12 MHz plasma etcher has an energy source, a cable to transfer the energy, and a chamber where the energy is deposited to do work; these are often all located in one cabinet. A surveyor always needs to be aware of these parts and their locations. Particular attention should be paid to the transmission path, which could pass through open air, an enclosed passage such as a microwave waveguide that could leak at joints or connections, or a fiber-optic cable that could be cut or broken.

SUBRADIOFREQUENCY FIELDS: 0–3,000 HZ

Because the distance where radiation is dominant is about one wavelength, fields, rather than radiation, are considered in this section. The wavelength of the highest frequency in this section, 3 kHz, is 100,000 m, or about 61 mi. Static fields do not produce radiation. As shown in Table 11–D, the subradiofrequency portion of the spectrum includes the extremely low frequency (ELF) band, which includes AC fields and radiation up to 300 Hz, and the voice frequency band, which includes frequencies from 300 to 3,000 Hz. Power lines use 50 or 60 Hz currents, which create fields at these frequencies; these frequencies are often called power frequencies.

Field Strengths

Electric fields can be measured by inserting a displacement sensor, a pair of flat conductive plates, into the field and measuring the electric potential between the plates. The electric field lines land on one plate and create voltage that drives a current through the meter to the other plate, where the field lines continue as shown in Figure 11–6. The electric field can be calculated by dividing the voltage between the two plates by the distance between the plates. If a 1-kV potential were found to exist and the plates were 1 m apart, then the electric field strength would be 1 kV/m; if the plates were 0.5 m apart and the potential were 1 kV, then the electric field strength would be 2 kV/m. Instruments like this are widely used for measuring electric fields at frequencies ranging up to 100 kHz.

Magnetic fields are often measured with loops of conducting wire, as shown in Figure 11–7. The lines of magnetic field passing through the loop induce current flow. The field can be calculated by measuring the amperes of induced current and dividing that by the circumference of the loop. The common unit of magnetic field strength in the United States was the gauss (G), but it is being replaced by an SI unit, the tesla (T): 1 T = 10,000 G, 1 mT = 10 G, and 1 μT = 10 mG. One G ≅ 80 A of induced current per meter of circumference of conducting loop (A/m).

How Do Fields Interact with the Body?

The body is a conductor of electricity, but it does not have well-known magnetic structures. (At the time this chapter was prepared, research suggested that microscopic magnetic structures exist in the human brain.) We have seen that electric charge imbalances are balanced as quickly as possible. Imagine you were below a high-voltage electric transmission line, as shown in Figure 11–8, and the line's polarity was positive. Your body would develop a corresponding negative charge because the positive charge above would attract any movable negative charge toward it. These charges would come from your body and from the infinite pool of charges

Table 11–D. ***Uses of Radiofrequency and Subradiofrequency Fields***

Frequency, v	*Wavelength, l*	*Name*	*Uses*	*ISM Bands Center Frequency and ± Range*	*Radar Band and Frequencies*	*WWII Radar Bands and Frequencies*
>300 GHz	*<1mm*	*Infrared*				
300 GHz	1 mm	EHF	Satellite communications, radio relay, navigation aids	None	M 60–100 GHz L 40–60 GHz	H 44–56 GHz Q 36–46 GHz
30 GHz	1 cm	SHF	Satellite communications, radar, fire, police speed guns (24.15 GHz)	22.125 GHz ±0.125 GHZ 5.86 GHz ±0.075	K 20–40 GHz J 10–20 GHz I 8–10 GHz H 6–8 GHz G 4–6 GHz	Ka 22–36 GHz X 5.2–10.9 GHz C 5.9–6.2 GHz
3 GHz	10 cm	UHF	TV 14–82, CB, taxi dispatch, radar, ovens, cellular phones	2.45 GHz ±0.05 915 MHz ±0.025	F 3–4 GHz E 2–3 GHz D 1–2 GHz	S 1.55–5.2 GHz L 0.36–1.55 GHz
>300 MHz	*<1 m*	*Microwaves*				
300 MHz	1 m	VHF	TV 2–13, FM radio, fire, police	40.68 MHz ±0.02	B 250–500 MHz A 0–250 MHz	P 220–390 MHz
30 MHz	10 m	HF	CB radio, diathermy (VDT flyback fields)	27.12 MHz ±0.16 13.56 MHz ±0.00678 (both used for plasma etch)	A	None
3 MHz	100 m	MF	AM radio, amateur radio, navigation aids	None	A	None
300 kHz	1 km	LF	Navigation aids, marine and long-range communications	None	A	None
30 kHz	10 km	VLF	Communications, long-range navigation, induction heating (flyback rate of VDTs)	None	A	None
<3 kHz	*>100 km*	*Subradiofrequency*				
3 kHz	100 km	Voice	Modulation, induction heating	None	A	None
300 Hz	1,000 km	ELF	Submarine communications, induction heating (electric power, refresh fields of VDTs)	None	A	None
0 Hz	DC					

you were standing on, the ground. The electric field lines would originate at the power line and land on your body. As the polarity reversed, the charge in your body would subside and reverse; the rush of negative charges into your body would be replaced by an exodus of negative charges, so you would take on a positive charge as the line overhead became negatively charged. The electric field lines are perpendicular to the conducting surface they end at or leave. The result of this perpendicularity phenomenon is that a person in an electric field created by a source above the person, such as a power line, distorts field lines in from nearby space so they land perpendicular to the head. As a result, the electric field around the head becomes highly concentrated and intense. At other regions of space, the electric field lines are spread further apart, lowering the field intensity. If this person was holding an electric field meter at waist height, the surveyor's body would largely shield it and the reading would be falsely low. The reading also could be falsely increased if the surveyor was the tallest object in the area and the field source was above the surveyor.

Magnetic fields are easier to measure, because the human body does not perturb the magnetic field as it perturbs the electric field. We are filled with conductive brine, so a magnetic field that changes with time induces loop-shaped current flows in a direction perpendicular to the field, as shown in Figure 11–3. The strength of the induced current is proportional to the strength of the magnetic field and the radius of the loop in which the current is flowing. The current at the center of the loop is zero and reaches a maximum level at the rim of the loop.

BIOLOGICAL EFFECTS AND STANDARDS FOR STEADY (DC) ELECTRIC FIELDS

Steady fields are created with charges and currents that do not change polarity or strength with time. Steady electric fields are not a significant area of concern today; in fact, no instrument is marketed that is intended for use in safety surveys for DC fields (although there are instruments that can be adapted for exposure surveys). The adverse effects identified by the Non-Ionizing Radiation Committee of the Inter-

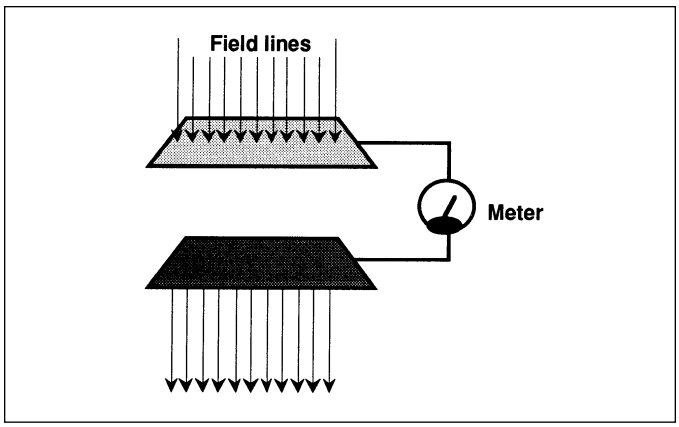


Figure 11–6. Displacement (split-plate) electric sensor used for AC field instruments in extremely low-frequency through medium-frequency regions (>0 Hz–3 MHz). Note that field lines impinge on the upper plate, drive a current through the meter, and reemerge at the other plate. The field strength is the voltage difference between the two plates divided by the distance (V/m).

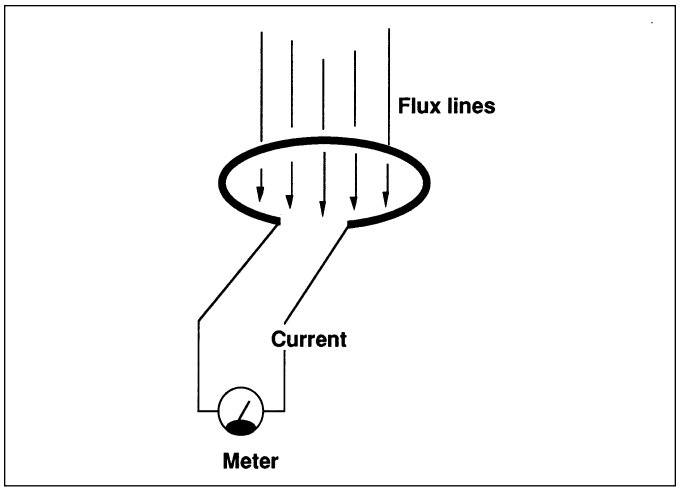


Figure 11–7. Most AC magnetic field survey instruments use looped conductors. The changing magnetic field induces a flow of current in the loop. The unit of field measurement is the amperes of current induced to flow through a specified distance of loop (A/m). The induced current is proportional to the sine of the angle between the loop and field. If the loop is parallel to the field, the sine of 0° is 0 and no current is induced to flow. If the loop is perpendicular to the field, as shown, the sine of 90° is 1, so the loop will give a maximum response. Thus, measurements made with one loop are highly directional. Rotating a loop like this in a magnetic field produces a sinusoidally changing current.

national Radiation Protection Association (now the International Commission for Non-Ionizing Radiation Protection, or ICNIRP) are as follows:

- ➢ Irritating sparks could occur at electric field strengths of 5 kV/m or more.
- ➢ Painful sparks could occur at electric field strengths of 15 kV/m.

The 2001 Threshold Limit Value (TLV®) for DC electric fields from 0 Hz to 100 Hz is 25 kV/m as a ceiling limit (a limit that should not be exceeded for any length of time).

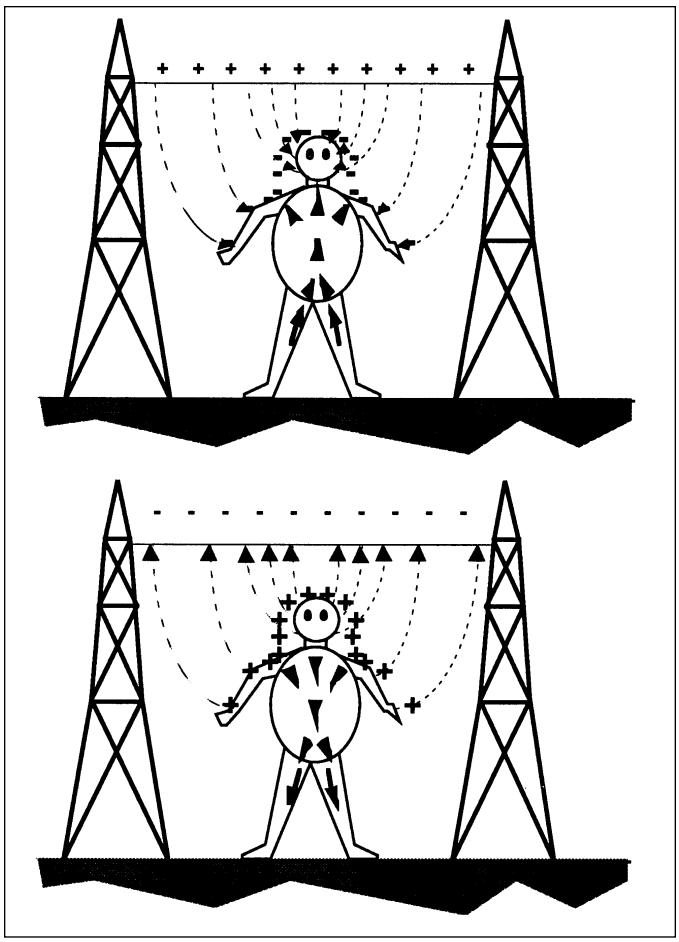


Figure 11–8. Induction of current by an external magnetic field. a. The overhead transmission line has a positive voltage. The electric force (dashed lines) induces negative charges to accumulate in the person's body. The negative charges enter the body as a flow of electrical current from the ground. This happens 60 times a second. b. 1/120 of a second later, the line's charge is negative, inducing a positive charge in the body created by a flow of electrical current into the ground. Radiofrequency fields can create similar current flows, but at higher frequencies. (Adapted from Nair, Morgan, and Florig, 1989.)

The field strengths in the TLV are the field levels present in air away from the surfaces of conductors (where spark discharges and contact currents pose significant hazards). It applies to both partial-body and whole-body exposures.

BIOLOGICAL EFFECTS AND EXPOSURE STANDARDS FOR STATIC MAGNETIC FIELDS

Magnetic effects are caused by charges in motion or changes in magnetic fields. The static fields from permanent magnets or superconducting magnets do not change with time, so any interaction would need to occur where charges are in motion. Blood is briny material, so magnetic field effects can be expected in the circulatory system where charges are in motion. The effect can be seen on an electrocardiogram

(ECG) made while an animal is in a static magnetic field. The entire output of the heart is pumped into the aorta at high speed. This flow induces a magnetohydrodynamic (MHD) voltage that appears on the ECG at the same time as the T wave of the heart. The added MHD voltage makes the T wave look bigger. The bigger the magnetic field, the bigger the T wave; when the magnetic field is shut off, the T wave reverts to normal.

Based on this effect, the current TLV® is 60 millitesla (mT), or 600 G, which is based on limiting the average MHD voltage to 1 mV. It is an 8-hour time-weighted average (TWA) criterion. The peak exposure is set at 2 T, based on medical imaging exposure limits. The International Commission for Non-Ionizing Radiation Protection announced guidelines for static magnetic fields in the January 1994 issue of *Health Physics* that retain the 2 T peak exposure limit but raise the TWA exposure limit to 200 mT (2,000 G). This change accounts for MHD voltage and is based on human experience and on the results of lifetime exposure studies involving mice exposed to 1 T, which demonstrated no effects. Humans exposed to 4 T fields are reported to experience symptoms such as nausea, metallic taste in the mouth, dizziness, and, when the head is moved, magnetic phosphenes.

Another effect is worth noting. Rotating the earth's magnetic field, which is usually about 0.5 G, disrupts the circadian rhythms of test animals and fluctuations in body function that are associated with time of day, such as hormone levels and body temperature. This is related to our sense of time, which is perceived as jet lag. This effect occurs if the animal is unaware of the day–night cycles around it, but even 9 T fields did not break the sense of time of animals aware of light–dark cycles. People who work in strong magnetic fields should avoid unusual shift work that causes them to lose track of day–night cycles.

Other Safety Concerns of Static Magnetic Fields

Before leaving static magnetic fields, it is necessary to consider two related issues: the effects on medical electronic devices and classic safety concerns. Artificial cardiac pacemakers work by amplifying the electrical activity of the natural pacemaker tissues of the heart. The electrical output of the pacemaker changes as the electrical activity of the heart's pacemaker tissue changes. Artificial cardiac pacemakers can be fooled by ambient electric and magnetic fields, including very strong AC fields. When this happens, they could amplify the AC fields instead of boosting the activity of the natural pacemaker, and the heart, now trying to work at 60 Hz, would not circulate blood. Pacemakers have built-in protective circuits that sense malfunctions and cause the pacemaker to send impulses to the heart at a fixed rate. The wearer tests these circuits in a cardiologist's office (or at home while in telephone/telemetry contact with a cardiologist) by changing the setting of a reed switch in the artificial pacemaker so it fires at the fixed rate. A permanent magnet held over the pacemaker is used to reset the reed switch. Thus, strong static fields could cause this reed switch setting to inadvertently change in places where no medical supervision is available. Magnetic fields stronger than 0.31 mT (3.1 G) could reset some very susceptible pacemakers, so a pacemaker safety criterion of 0.5 mT (5 G) has been set; this criterion may be revised to 0.3 mT in the near future.

Magnetic fields exert forces on objects that can be magnetized. The degree to which material can be magnetized depends on its permeability. Aluminum, stainless steel, plastics, and organisms are not permeable. Soft iron, steel, and various transition metal alloys (such as those of nickel and cobalt) are permeable. Tools and some medical implants are made of permeable alloys so they can move in a strong magnetic field. The force of such a field is proportional to the strength of and gradient of the field (the rate at which that field changes intensity through some part of space). A steel wrench in a perfectly uniform super-strong magnetic field would not move because there is no gradient, but it would move as it was taken from the strong field through a weak field. The force is also proportional to the object's permeability and volume. A nonpermeable stainless steel wrench would not move even in a strong and rapidly changing field. Thus, tool and compressed gas cylinder controls, and limits on workers with metal prosthetic implants, are needed. The simplest test devised to locate hazardous locations is to tie a washer or other small permeable object to a string and tie off the other end to a belt loop and watch for places where the washer is pulled out by magnetic fields. Stainless steel, widely used in prosthetic implants, is normally nonpermeable but can be made permeable where it is machined. The ICNIRP advises that mechanical hazards due to flying tools and movement of metallic medical implants become a potential hazard when fields are as low as 3 mT (30 G). The ICNIRP also advises that magnetic media, such as the magnetic stripes on the backs of credit cards and diskettes, can be erased by fields above 1 mT (10 G).

BIOLOGICAL EFFECTS AND EXPOSURE STANDARDS FOR TIME-VARYING SUBRADIOFREQUENCY FIELDS

Time-varying fields have emerged as an area of concern because of widespread fear that they may lead to cancer. The initial concern arose as a result of epidemiological studies. These studies are not discussed further here because they are sufficiently diverse in their findings as to leave reasonable doubt. A large body of research results from in vivo and in vitro experiments has accumulated about the possible biological effects of such fields, but much of it is contradictory. The Bioelectromagnetics Society issued a primer on biophysics and exposure systems to assist researchers in 1993. The National Institute of Environmental Health Sciences (NIEHS) conducted a comprehensive review of the literature on health effects, and found limited evidence of any concern.

It is now generally, but not universally, accepted that power line fields can influence cell membranes. This effect is observable as an increase in the rate at which calcium ions are moved from the inside of a cell through the cell membrane to the outside. The possible effects of these interactions are potentially far-reaching and include promotion of tumor growth, but adverse effects have not been demonstrated in replicated experiments at the time this chapter was written.

It is also generally accepted that power line fields affect circadian rhythms much as static fields do. Recent research suggests that the prolonged exposures do not exert this effect; rather, the rapid changes that occur when the field is turned on and off exerts the effect. Circadian rhythm is controlled by the pineal gland, located in the center of the brain. The pineal receives electrical impulses from the eyes via the suprachiasmatic nucleus, located where the optic nerves cross. The pineal secretes melatonin at night. It has been speculated that altered pineal function could reduce the ability of the immune system to eliminate infections or tumors, but this has not been proven at the time this chapter was written.

Before setting science-based exposure standards, it is necessary to demonstrate a mechanism by which the fields exert their effects on living tissue. The one well-established mechanism of interaction is based on current flow through tissue, which can cause stimulation of nerves and muscles, and tissue heating. Many possible alternative mechanisms have been proposed, but none have been proven. This uncertainty about mechanisms is important because some of the proposed mechanisms do not involve either of the classic dose-response models. It is possible that moderate field intensities are hazardous whereas stronger or weaker fields are not hazardous. Regulations have assumed that less is safer, so the possibility of windowed effects is something regulators have not seen before.

The standards that do exist are based on the known effects of currents induced in the body. According to *WHO Environmental Health Criterion 69, Magnetic Fields,* the following associations can be drawn between induced currents and reported biological effects:

Induced Current Density (mA/m^2)	*Effect*
<1	None established
1–10	Minor biological effects
1–10	Magnetophosphenes, possible nervous system effects, enhancement of bone fracture healing
1–10	Changes in CNS excitability, stimulation thresholds, possible health hazards
>1,000	Extra systoles, possible ventricular fibrillation, definite health hazards

Health regulations fall into two broad categories: exposure criteria, which specify how much a person can be exposed to, and emission criteria, which describe how much can be released into or be present in the environment near a source. Both types of regulations exist for nonionizing radiation. The ICNIRP has issued general public and occupational exposure criteria based on induced current flow considerations, as shown in Table 11–E.

The American Conference of Governmental Industrial Hygienists (ACGIH) also issued TLV® exposure criteria for workers, based on avoiding induced currents that are stronger than those that already exist in the body due to the normal functioning of nerves and muscles. A number of states have established emission criteria for power transmission lines by specifying maximum fields that can exist along the edges of the right of way occupied by a power transmission line. These tend to be around 20 μT (200 mG) for magnetic fields and 1 kV/m for electric fields.

The clamor for action has prompted researchers and regulators to develop a number of ideas. Two are worth noting. The first, prudent avoidance, relies on reducing magnetic fields when possible by means that do not involve great expense, similar to the As Low As Reasonably Achievable (ALARA) concept applied to reducing ionizing radiation exposures. The second, 2 mG, is an averaged exposure level used to define high average exposure scenarios in epidemiological studies. It may not define the field strengths that might actually cause harmful effects; such levels could be much higher. Thus, caution is advisable when deciding whether to apply the prudent avoidance or 2 mG approaches in the absence of definitive scientific data.

Before leaving biological effects, it is necessary to return to the subject of pacemakers. The ICNIRP advises that power frequency AC fields could interfere with normal pacemaker function at field strengths of 2 kV/m and 1 G. This is because such fields create potentials that the pacemaker could confuse with the heart's natural electrical activity, which has a similar ELF frequency. The ACGIH advises that pacemakers could be influenced by 1 kV/m electric fields and 1 G magnetic fields. There is no generally accepted guidance about how to address this potential hazard.

MEASURING SUBRADIOFREQUENCY FIELDS

Electric fields are measured using variations of the displacement sensor described earlier. The surveyor must stand away from the detector when measuring electric fields because the surveyor's body will shield the detector and create a falsely low measurement. Thus, these instruments come with long nonconductive handles so they can be held as far from the operator's body as possible. One vendor supplies a long pole, one supplies a long handle and instructs the surveyor to hold the detector as far away as possible and to use a fiber-optic readout, and a third uses an electrician's hot stick. The sensors of these instruments resemble paddles or clamshells, with a nonconducting seam separating the shell halves. These instruments are directional; that is, they do not respond equally to fields coming from all directions. These instruments must be

Table 11–E. ***Exposure Criteria for DC and Subradiofrequency Fields***

				Exposure Criterion	
Frequency	*Exposure Group*	*Exposure Duration*	*Exposed Part of Body*	*Electric (kV/m)*	*Magnetic (mT)*
Static	Occupational	8-hr shift	Trunk		200*
Static	Occupational	<8-hr shift	Limbs		5,000
Static	Occupational	Ceiling	All		2,000
60 Hz	Public	24-hr day	All	5	0.1 (80 A/m)†
60 Hz	Public	<24-hr**	All	10	1 (800 A/m)†
1 Hz–300 Hz††	Occupational	Ceiling‡	All		60/f (600/f G)‡
1 Hz–300 Hz††	Occupational	Ceiling‡	Extremities		300/f (3,000/f G)‡‡
DC to 100 Hz	Occupational	Ceiling‡	All	25	
100 Hz–4,000 Hz§	Occupational	Ceiling‡	All	2,500/f‡‡	

* Time-weighted average.
** Peak allowed for times below 24 h as long as the average exposure during an 8-h shift does not exceed 5 kV/m or 0.1 mT (1 G).
† 1 mT = 10 G ≅ 800 A/m.
†† ACGIH considers frequencies <30 kHz to be subradiofrequencies, but their standard matches the 163 A/m standard of ANSI/IEEE C95.1-1991 at a frequency of 294 Hz, which ACGIH rounds up to 300 Hz. ACGIH advises that pacemakers can malfunction at field strengths of 0.1 mT (1G), but only at 50 and 60 Hz.
‡ Maximum exposure allowed for any time period.
‡‡ Frequency in Hz.
§ ACGIH considers frequencies <30 kHz to be subradiofrequencies, but their standard matches the 614 V/m standard of ANSI/IEEE C95.1-1991 at 4,071 Hz, which ACGIH rounds down to 4,000 Hz. ACGIH advises that pacemakers can malfunction at field strengths of 1 kV/m, but only at 50 and 60 Hz.

held so that the electric field is perpendicular to the paddle or to the seam between the clam shells. The reading reaches a peak level when the sensor is aligned properly.

Magnetic fields are measured with loops. The induced current can be boosted by increasing the number of wire turns in the loop or by putting a core of permeable material in the loop. Loops are highly directional. The current induced in a loop reaches a peak value when the loop opening is perpendicular to the flux lines of a magnetic field and does not respond when the opening is parallel to the lines of flux. The response is proportional to the sine of the angle between the loop opening and the flux lines. (The sine of 0° is 0, the sine of 90° is 1, and sine values cannot be higher than 1.)

When using a single-loop detector, it is necessary either to know how the field is oriented (from a knowledgeable person or other reliable source) or to measure the field with the detector pointed in one direction, then in another perpendicular direction, and finally in a third direction perpendicular to the other two. The center of the detector must be the same for these three measurements. The field is estimated by taking the squares of each measurement, adding the squares, and by taking the square root of the sum of the squares. This calculation is easily done using a spreadsheet.

A word of caution about loops: An instrument using a loop or coil sensor will display the average magnetic field in the area surrounded by the loop; magnetic fields at specific points in the loop may be different.

Another method of magnetic field measurement relies on the Hall effect. An object with a current flowing through it in a magnetic field will develop a voltage in a direction perpendicular to the magnetic field, which can be measured. Hall effect sensors are less sensitive than loops, but are used for DC field surveys where concern begins at a few G, whereas AC field concerns begin at 1 mG or less. Hall effect instruments also read super-strong tesla strength fields. Hall effect probes come in axial response and transverse response types. Transverse response probes are handled just like the single- axis loops just mentioned; peak response occurs when the field is perpendicular to the flat side of the tip of the sensor blade. Axial probes are aligned to give peak response when the field is parallel to the long axis of the probe, so the measurement protocols mentioned earlier must be modified to account for the fact that the peak response occurs when the field is parallel with, rather than perpendicular to, the probe. A personal dosimeter is now available that has three mutually orthogonal Hall effect sensors for isotropic response.

Loops are often ganged together in mutually orthogonal arrays of three loops so that the detector does not operate in a directional manner; such an instrument is shown in Figure 11–9.

Magnetic field survey instruments using orthogonal triple-loop detector arrays are now available for all frequencies of interest. Orthogonal loops (or Hall effect sensors) confer isotropic response; that is, the response is about equal for all probe orientations in the field and the sensor is largely nondirectional.

Field loggers, often called dosimeters, are available for ELF magnetic field measurements. The EMDEX loggers for ELF fields were developed for the Electric Power Research Institute and closely resemble modern audio dosimeters in the kind of data they provide. They use mutually orthogonal loop sensors (for time-varying fields). The EMDEX loggers read out through a computer to provide a minute-by-minute summary of exposures in all three axes plus the overall field. Several vendors offer wheeled harnesses for EMDEX loggers, which can be used to precisely map locations when the logger is used to log field strengths at various points in a measurement area.

CONTROLS AND SHIELDING

Stopping electric fields is easy. Imagine that a person is standing below a power transmission line. If a sheet of conductive material were placed between the person and the source and that conductor were grounded, induced charges would flow between the conductor and the earth. As a result, the field lines would begin at the conductor above the person, induce current flow in the sheet through the ground, and not reach down to the person. The material can be solid, but mesh will do as long as the opening of the mesh is smaller than about 1/4 wavelength. This means that chicken wire will block a 60 Hz electric field. Operational shields must be grounded in accordance with electrical safety codes. A practical result of the ease of blocking electric fields for surveyors is that the electric fields in most structures are created by appliances inside the structure, even if a high-voltage transmission line passes overhead.

Shields used to block magnetic fields are different from other forms of shielding, which work by stopping an agent with a barrier. Magnetic fields are controlled using permeable alloy that confines the magnetic flux lines and diverts them. Recall that magnetic fields exist as circuits; they do not reach out into space as electric field lines and radiation do. Magnetic shielding can be made using high nickel alloys called mu metal or soft iron. Forming mu metal into complex shapes is expensive and mu metal is easily damaged. Magnetic field shielding alloys are less permeable at low field strengths than at high field strengths, so they work best at high field strengths. Such shielding is best applied near the field source, whenever practical. Materials that work at lower magnetic field strengths could become commercially available in the future. Another approach is to use nonpermeable metals such as copper or aluminum to produce eddy currents that cancel out the original magnetic field.

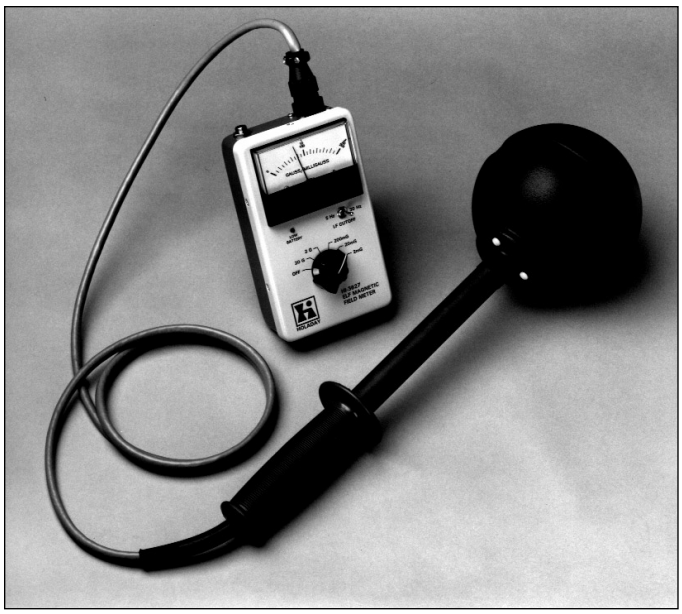


Figure 11–9. Loops are often ganged together in mutually orthogonal arrays of three loops. (Courtesy Holaday Industries, Inc.)

Exposures of people to magnetic fields is routinely but unintentionally reduced by canceling fields, as in appliance cords with closely spaced conductors. If a current flows in one direction through a conductor, say from the power outlet in a wall to an appliance, and back in the opposite direction through the conductor next to the first one, each conductor creates a magnetic field, but the orientations of the fields are opposite and the fields nearly cancel each other out. The closer the two conductors are, the more cancellation occurs. Overhead power lines use widely spaced conductors to avoid arcing, so relatively little cancellation occurs compared with underground power lines, where the insulated conductors are close together. This is why magnetic fields around underground lines are lower than those of overhead lines. Soil has no shielding value for magnetic fields although, as a conductor, it does block electric fields.

Field cancellation technology is being increasingly used for AC fields. Some low-field video display terminals (VDTs) use it in the form of additional field coils next to the coils that steer the electron beam to create a canceling field. Utilities can rewire transmission lines to obtain more cancellation. One utility company has developed a technique for creating canceling fields around transmission lines. Field cancellation may also prove useful in households where poorly wired appliances are leaking currents to the ground. The current leaving a house through the ground often does not enter where the current entered the house, so it cannot cancel the magnetic fields created by the incoming current. A house with leaking appliances can have two magnetic hot spots: one where the service enters the house and the other by the ground carrying the leakage current, as shown in Figure 11–10. Any changes made to household wiring to reduce magnetic field exposure must comply with electrical safety codes. It may be necessary to change electrical safety codes if 60 Hz magnetic fields prove to be hazardous.

RADIOFREQUENCY/MICROWAVE RADIATION AND FIELDS (RF/MW)

This portion of the electromagnetic spectrum covers a huge range of frequencies, from 3 kHz to 300 GHz or wavelengths ranging from 100 km to just 1 mm. Recall the earlier section about when fields are important and when radiation is important. Some RF/MW scenarios involve fields and others involve radiation. It is generally agreed that radiation is likely to be found at frequencies above 300 MHz (wavelength = 1 m) whereas fields are likely to be found at lower frequencies. The practical consequence of this is that two surveys, one for electric fields and the other for magnetic fields, are required at lower frequencies but only one survey is needed at higher frequencies.

See Table 11–D for a summary of divisions and uses of the RF/MW portion of the spectrum, which includes very low frequency or VLF (3–30 kHz), low frequency or LF (30–300 kHz), medium frequency or MF (300 kHz–3 MHz), high

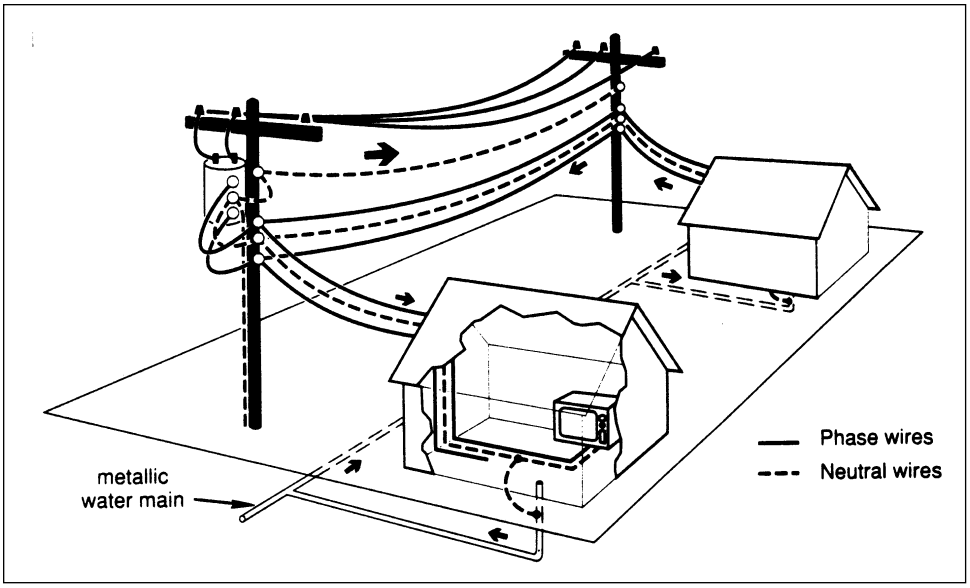


Figure 11–10. Current can leave a house next to where it came in, in which case there is good field cancellation. If an appliance is poorly grounded, however, some current leaves through the ground and returns to the utility by flowing through the earth. The current flow into the house is not balanced and canceled by the return current, so the magnetic fields are higher at the unbalanced supply wires and where the current flows into the ground. The phase wires bring the current in and the neutral wires return it. (Reprinted from Electric Power Research Institute, *Electric and Magnetic Field Fundamentals—An EMF Effects Resource Paper.*)

frequency or HF (3–30 MHz), very high frequency or VHF (30–300 MHz), ultrahigh frequency or UHF (300 MHz–3 GHz), super high frequency or SHF (3–30 GHz), and extremely high frequency or EHF (30–300 GHz). Microwaves are the portion of the radiofrequency spectrum ranging from 300 MHz to 300 GHz; strictly speaking, the radiofrequencies extend from 3 kHz to 300 GHz.

Industrial, Scientific, and Medical Bands and Frequency Nomenclature

A band is a part of the entire electromagnetic spectrum. Safety and health specialists often find equipment working in the industrial, scientific, and medical (ISM) bands, which anyone can freely use because no licensing is required. The most popular ISM band is the 2.45 GHz band used by microwave ovens. Electrical engineers often use the traditional band designations originally used for radars and military electronics in World War II. Thus, you may hear or read about a Ka band police radar speed gun that works at 24.15 or 35 GHz. These designations were not user-friendly; the modern designation system uses letters of the alphabet, in ascending order, to describe increasing frequencies. For example, the MiG-25 radar operates in the J band, which is somewhere between 10 and 20 GHz. Table 11–D lists the ISM bands and the traditional and new band designations.

Interactions of Radiation and Matter

The interactions of radiation and matter can be described in terms of how much energy in the radiation is lost to the matter it strikes, as shown in Figure 11–11. If all of the energy in the radiation is lost to the matter, it is absorbed. If some energy, but not all, passes from a chunk of matter, then the radiation is scattered because the remaining, less energetic radiation often leaves in a different direction. If none of the energy is lost, then the radiation was transmitted. Electrical engineers call objects such as radio broadcast towers and radar sets emitters rather than transmitters. Finally, radiation does not pass from one medium to another when the electrical properties are too dissimilar. When this occurs, the radiation is reflected back into the medium it came from. Reflection is the basis of radar; controlling reflections from mirrors and other shiny objects is a major concern in laser safety.

RF/MW that is absorbed or scattered can impart energy to living matter by induction of current flow, which in turn encounters resistive parts of tissues such as cell membranes, or by interactions between the electric field and charged portions of water or organic molecules such as proteins. Electrically charged portions of molecules can be caused to vibrate and ions of metals dissolved in water can be caused to move in response to the electric fields. In both cases, the energy finally appears as heat.

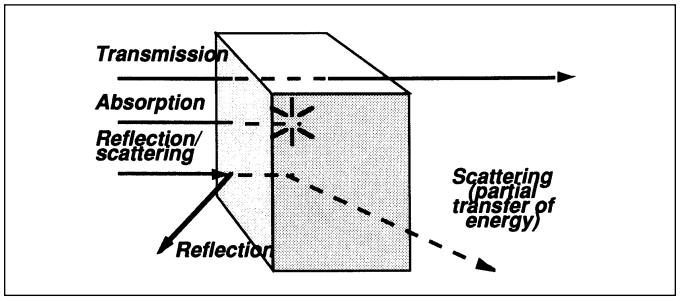


Figure 11–11. Electromagnetic energy can be completely absorbed by matter (absorption), pass through without any interaction (transmission), lose some of its energy (scattering), or not enter at all (reflection). Reflection occurs when the electrical properties of the material the radiation comes from and those of the material it strikes are too different. Radar works when electromagnetic radiation in air, a fair insulator, strikes metal, a superb conductor.

BIOLOGICAL EFFECTS AND EXPOSURE STANDARDS FOR RADIOFREQUENCY FIELDS

The status of biophysics research in the radiofrequencies is somewhat more certain that it is for the subradiofrequencies. More research is needed to answer concerns about the safety of radiofrequency energy used by devices such as VDTs (which use ELF fields in the 60 Hz range and VLF fields in the 20–30 kHz range), cellular phones (which work around 840 MHz), wireless office technology (which uses the 915 MHz ISM band), and police radars (which have used 10, 24.15, and now 35 GHz). A great deal of research has been conducted and more is under way. The research has been sufficient to develop generally accepted safety standards. Radiofrequency and microwave energy causes a wide variety of biological effects (summarized in Table 11–F), especially if exposures are intense enough to cause significant heating. The health significance of doses that are not sufficient to cause measurable heating (athermal effects) is uncertain.

Table 11–F. ***Biological Effects Reported for Radiofrequency and Microwave Radiation***

Target Organ/ Overall Effect	*Effect*	*Exposure*
Eyes (animals and humans)	Cataracts	Hours at 120 mW/cm^2
	Keratitis	40 mW/cm^2
Behavioral (animals only)	Various test changes	≥1.1 W/kg
	Behavioral thermoregulation	≥1.1 W/kg
Endocrine (animals only)	Corticosteroid and thyroid increases	>8.3 W/kg
Immune (animals only)	B and T cell activity changes	≥1.4 W/kg
Neurological (animals only)	Tests of blood/brain barrier contradictory	
Mutations	Not found in replicated studies to date	
Cancer	Not found in humans or animals to date	
Reproduction	Temporary male sterility	5.6 W/kg
	Testicular changes	≥15 W/kg
	Leutenizing hormone changes	>2 W/kg
Teratology (animals only)	Malformed offspring	≥31 W/kg
Thermoacoustic/ inner ear (pulsed only)	Observed in radar operators in WWII as perceived clicking sound while in beam	
	Possible cause of neurological effects observed in test animals	0.6 W/kg

Dosimetry

It is not enough in radiofrequency biophysics research to state that rats were exposed to 10 mW/cm^2 of 2.45 GHz continuous wave radiation and certain effects were observed. Researchers must address physics problems that determine how the power density in the rats' ambient environment turns into power deposited in the rats' tissues. The issues to be addressed are the size of the organism compared with the wavelength of the radiation, the polarization of the radiation (how the electric field is aligned to the earth's surface) as compared with the orientation of the exposed organism, and the interaction of exposed tissues with the radiation or fields. The response of tissue to radiation and fields is determined by the electrical properties of the tissue. The discipline that addresses this concern is RF/MW dosimetry.

The dose rate (rate at which energy is transferred to tissue) is called the *specific absorption rate* (SAR), expressed in watts of power deposited per kilogram of tissue (W/kg). The term for the quantity of energy transferred to tissue is specific absorption (SA), expressed in joules of energy per kilogram (J/kg) of tissue. Note that energy is equal to power times time. Power is expressed in watts and 1 watt times 1 second equals 1 joule of energy. One kilowatt hour of energy use equals 3,600 s × 1,000 W, or 3.6 million J. Joules are used in exposure standards for pulsed laser energy.

An organism acts as an antenna. An object absorbs the most radiation energy if it is about 40 percent of the wavelength and not well-grounded or when it is about 20 percent of the wavelength and well-grounded. Thus, the resonant frequency for a rat is much higher than for a human. Present regulations assume that peak absorption, or resonance, occurs at frequencies of 30–300 MHz. At lower frequencies (<30 MHz), absorption diminishes in proportion to the square of the frequency so the object absorbs 25 percent as much radiation at 50 percent of the frequency and 1 percent as much radiation at 10 percent of the frequency. At higher frequencies (>300 MHz), absorption also falls off for a while and then flattens out at about 8 percent of that at the resonant peak. This is illustrated in Figure 11–12.

Another significant factor is polarization. Radiofrequency radiation is absorbed most when the electric field is parallel to the long axis of the organism and is absorbed least when the magnetic field is parallel to the long axis of the organism, as shown in Figure 11–13. Rats typically best absorb horizontally polarized radiation whereas upright humans best absorb vertically polarized radiation. Some absorption occurs within "H" (magnetic field).

Dosimetry can be done by measurement or mathematically. Measurement dosimetry was hampered by using common thermocouples, which include a pair of conducting wires trailing from the object being tested. The wires interact with the electric fields so only one temperature measurement could be made even in a human-sized object. Fiber-optic devices are now available so several concurrent temperature measurements can be made in one animal. Another way of

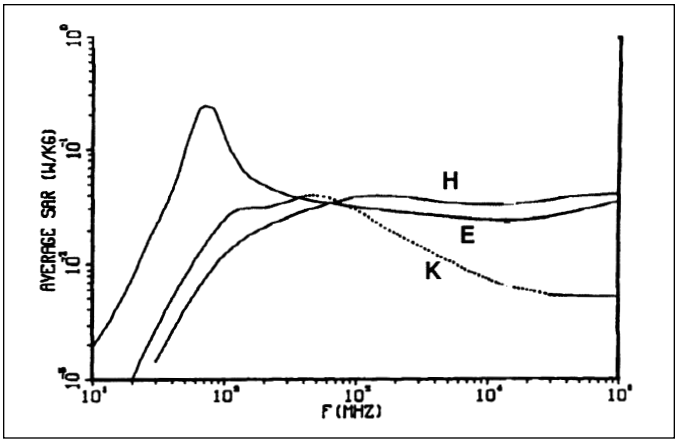


Figure 11–12. Specific absorption rates (SAR) for humans as a function of frequency. The letters *E*, *H*, and *K* show that the radiation is aligned so the electric field axis points along the long axis of the organism (vertically polarized), the magnetic field points along the long axis of the organism, and the radiation travels through the long axis of the organism. *E* = electric field, *H* = magnetic field, and *K* = direction of travel. Note that there are three major regions. In the *subresonant region,* the body does not function well as an antenna. Absorption drops in an inverse square relationship to wavelength. In the *resonant region*, the body is a good antenna that maximizes absorption. In the *superresonant region* (6–300 GHz), the body no longer acts as a good antenna and absorption levels off at about 10 percent of peak absorption. Quasi-optical focusing occurs from 6 to 15 GHz and skin absorption predominates at >15 GHz (penetration <1 cm).

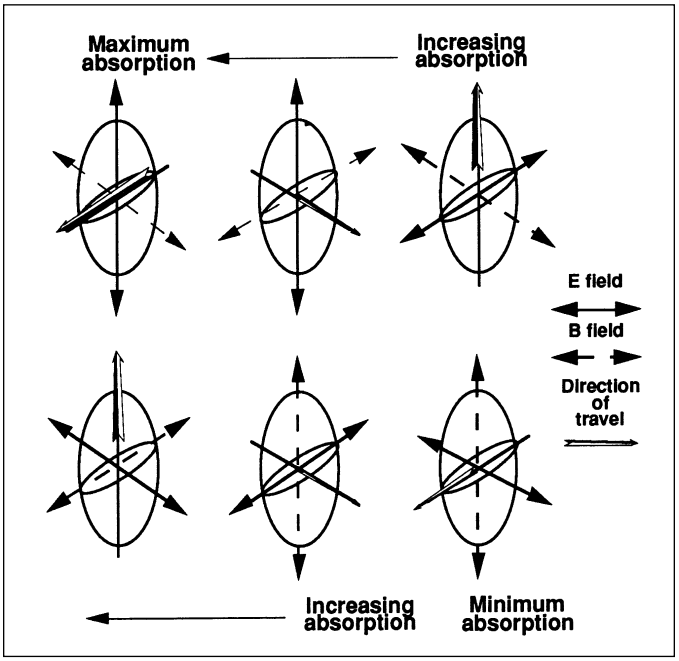


Figure 11–13. An elongated object (prolate spheroid) absorbs the most energy when the electric field is parallel to its long axis and the least energy when the magnetic field is parallel to its long axis.

making dosimetric measurements is to sacrifice animals and cut the remains in two longitudinal halves. The halves are joined, irradiated at intense levels, separated, and the temperature change is measured using an infrared device. The irradiation takes place in the same place as the irradiation of live animals, but at higher levels to produce more easily measured heating.

Mathematical dosimetry is also progressing. Early efforts were limited by computer capacity and by the need to use immense amounts of computer memory. Newer mathematical models make more efficient use of computer memory and supercomputers offer adequate capacity to do complex, tedious calculations. The original models used to develop the relationships just described between wavelength and polarization and the size and orientation of the organism simply estimated the average whole body SAR. Newer models estimate the SAR for specific organs and parts of the body. This will make it easier to interpret the results of future animal experiments. The University of Utah pioneered the development of mathematical dosimetry with funding from the U.S. Air Force School of Aerospace Medicine and published a series of dosimetry handbooks.

The leading dosimetric standard in the United States today is 0.4 W/kg as a whole body average. This objective is based on heat avoidance behavior of animals at an SAR of 4 W/kg, divided by a safety factor of 10. Higher local SARs are permitted (8 W/kg for specific parts of the trunk and nonextremity parts of the body and up to 20 W/kg at the extremities).

Target Organs

A variety of effects are known to occur at SARs above 4 W/kg, but the target organs are the eyes and testes, based on limits of circulation and heat dissipation at these two organ systems. It is assumed that the thermal equilibrium time for these target organs could be as brief as 6 min, so the standards specify exposure limits that apply for 6-min time intervals (until the frequency rises above 15 GHz, where the time interval gradually drops to 10 seconds). The only proven adverse effects for humans, regardless of SAR, are eye cataracts, facial burns, and electric shocks and burns. Cataracts occur in animals at power densities above 120 mW/cm^2 if the exposures last for hours, but only minutes of exposure are needed at 350 mW/cm^2. Electric shocks and strong current flows through the ankles have occurred in humans and are important at frequencies below 100 MHz. Other effects have been demonstrated in animals, such as teratogenic effects in animals subjected to intense SARs and neurochemical and eye effects in animals exposed to pulsed radiofrequency and microwave radiation, but these effects have not been duplicated in humans.

Standard-Setting Rationale

We can now see that the radiofrequency portion of the electromagnetic spectrum can be divided into three major parts,

as shown in Figure 11–14. At lower frequencies, current flow considerations dominate. The goal of the standard is to prevent burns caused by radiofrequency electric current (at frequencies of a few MHz and below) and excessive ankle heating caused by the surge of electricity to and from the ground through the feet (from a few MHz through the resonant frequencies). There was no convenient way to measure contact current until about 1991. Regulators approached the problem by limiting the ambient field strengths allowed to strengths that were equivalent to 100 mW/cm^2 if the fields existed as electromagnetic radiation. The risk of electrical burns caused by touching an object energized by radiofrequency fields and the risk of significant ankle heating are covered by current flow criteria.

At the resonant frequencies, where our bodies act as good antennas, controlling SAR becomes the main concern and remains a serious concern at higher frequencies until skin absorption becomes dominant. For regulatory purposes, the resonant portion of the spectrum ranges from 3 MHz (for electric fields) or 100 kHz (for magnetic fields) to 3 GHz and is most restrictive at frequencies ranging from 30 to 300 MHz, wavelengths where an adult or child functions as a good antenna.

At higher frequencies (above 3 GHz) skin absorption predominates and mathematical modeling reveals that absorption is about 8 percent of absorption at the resonant peak. Above about 6 GHz, most of the radiation is absorbed in the skin and outer tissue layers; at frequencies above 15 GHz, most radiation is absorbed in the first centimeter of tissue. The properties of microwaves become similar to those of infrared (IR) radiation and thermal damage to the skin becomes a major concern.

The regulatory community also had examined the question of how magnetic fields should be regulated in near-field scenarios. Magnetic fields passing through conductors induce current loops, as discussed in the ELF section of this chapter. Based on this and calculations of the current density induced by magnetic fields, it was agreed that magnetic fields would be subject to relatively lenient regulations.

Separate criteria were set for the general public and for occupational exposures. All earlier versions of the Institute of Electrical and Electronic Engineers' C95.1 standard, *American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields*, did not differentiate between occupational and nonoccupational exposures. For frequencies from 1.34 MHz to 15 GHz, nonoccupational standards are generally five times more restrictive than occupational standards. The Institute of Electrical and Electronic Engineers (IEEE) replaced the general public and occupational standards approach used for chemicals with an uncontrolled access versus controlled access approach, which allowed higher exposures for those who knew they were being exposed and could be provided with hazard awareness information, warnings, and training.

The standards are presented in Tables 11–G, 11–H, and 11–I. These are whole-body average exposures that are calculated based on measurements made at 20-cm vertical intervals beginning at the floor and reaching to the head at distances of 20 cm or more from radiating or energized objects.

Averaging Time and Pulsed Fields

Industrial hygienists are used to thinking in terms of 8-h time-weighted averages or 15-min intervals for short-term exposure limits. Radiofrequency standards rely on another interval, the thermal equilibrium of the target organs (the

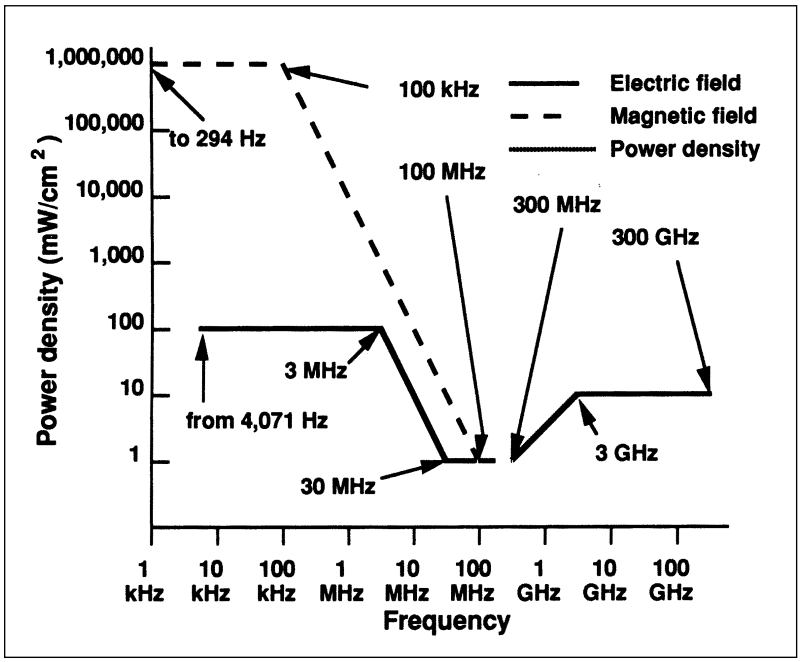


Figure 11–14. The inverse of the absorption curves shown in Figure 11–12. These are the C95.1 standards, which are most stringent in the frequencies where absorption is at its peak and level off at higher frequencies. The leveling off at lower frequencies reflects the risk of RF electric burns caused by contact with conductors immersed in strong fields. The *subresonant region* (<3 MHz) is the region in which current flow considerations are most important. In the *resonant region* (3 MHz–6 GHz), current flow and SAR are both important considerations where current is ≤100 MHz. Absorption falls off in proportion to the square of the frequency between 3 MHz and 30 MHz. Standards are most stringent between 30 MHz and 300 MHz. Between 300 MHz and 3 GHz, absorption falls off linearly as frequency increases. The *superresonant region* ranges from 3 GHz to 300 GHz. (From ANSI/IEEE C95.1-1991, 1992.)

Table 11–G. *Exposure Standards for Radiofrequency and Microwave Radiation and Fields Where Access is Controlled*

Part A: Electromagnetic Fields*

			Power Density, S (mW/cm^2)		
Frequency Range (MHz)	*Electric Field E (V/m)***	*Magnetic Field E (A/m)***	*E*	*H*	*Averaging Time E^2, H^2, or S (min.)*
0.000294†–0.1	—	163	100	1,000,000††	6
0.004071†–0.1	614	—	100	1,000,000††	6
0.1–3.0	614	$16.3/f_m$	100	$10,000/f_m$††	6
3–30	$1,842/f_m$	$16.3/f_m$	$900/f_m^2$	$10,000/f_m^2$††	6
30–100	61.4	$16.3/f_m$	1.0	$10,000/ff_m^2$††	6
100–300	61.4	0.163	1.0	1.0	6
300–3,000	—	—	$f_m/300$	$f_m/300$	6
3,000–15,000	—	—	10	106	6
5,000–300,000	—	—	10	10	$616,000/f_m^{1.2}$

Part B: Induced and Contact Radiofrequency Currents

	Maximum Current (mA)		
Frequency range (MHz)	*Through Both Feet*	*Through Each Foot*	*Contact*
0.003–1	$2,000f_m$	$1,000f_m$	$1,000f_m$
0.1–100	200	100	100

* The exposure values in terms of electric and magnetic field strength are obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).
** f_m = frequency in MHz.
† ANSI/IEEE C95.1-1991 covers frequencies between 3 kHz and 300 GHz; at 294 Hz and 4,071 Hz, C95.1 magnetic and electric field standards match the subradio-frequency TLVs.
†† These plane-wave equivalent power density values, though not appropriate for near-field conditions, are commonly used as a convenient comparison with maximum permissible exposures at higher frequencies and are displayed on some instruments.
(From ANSI/IEEE C95.1-1991, 1992.)

eyes and testes), which is assumed to be 6 min. Thus, time-averaging calculations can be made much as they are for chemicals, but the exposures must not exceed the C95.1 limit over a 6-min interval rather than an 8-h shift. Put another way, a person can be exposed to twice the limit for 3 min if no other radiation exposures occur for the other 3 min. The averaging interval for uncontrolled exposure situations is 30 min for frequencies ranging between 3 MHz and 3 GHz. IR exposures at the end facing microwave radiation are set at 10 mW/cm^2 for 10 s, so the averaging time changes from 6 min to 10 s for frequencies between 15 and 300 GHz.

The idea of limiting above-average exposures so the 6-min time-weighted average is below the standard has limits. Much as the chemical TLV® committee has attempted to address the topic of brief but intense exposures above a TLV, the C95.1 committee considered pulsed electromagnetic radiation and fields. Pulsed fields are common and recent military devices that simulate the pulses from nuclear weapons stimulated public concern about pulsed electromagnetic fields. As with chemical exposures, a simple TWA allows for extremely intense exposures if they are brief enough. Thus, an exposure to a 360-ns pulse could be a billion times more than the C95.1 limit if there were no other exposures for 6 min. The resolution has been to limit electric fields to 100 kV/m and to ensure that the power density does not exceed that given by the following formula:

$$\frac{(\text{cw limit of table 7 or 8} \times \text{average time of Table 11–F or 11–G in secs})}{(5 \times \text{pulse width in secs})} \quad (1)$$

The Europeans, led by Finland, are in the process of adopting pulsed field standards. The proposed standard sets limits on electric fields induced in the body by external pulses. Application of this standard entails resolving how pulses behave when they enter tissue and calculating the induced fields that result. Further developments in regulations for exposures to pulsed fields and radiation can be expected.

Regulatory Considerations

The standard paperback volume of Title 29 *Code of Federal Regulations* (*CFR*), Part 1910, the OSHA general industry regulations, includes the original 1970 radiofrequency/microwave exposure standard, 29 *CFR* 1910.97. This standard, based on ANSI C95.1-1966, is obsolete. The original regulation was struck down by the Occupational Safety and Health Review Commission in 1981, but the *UAW, Brock v. General Dynamics Land Systems Division* decision allows OSHA to apply state-of-the-art standards developed by others when OSHA has no standard of its own. IEEE adopted a revision of C95.1 in 1992 as IEEE C95.1-1991 and the American National Standards Insti-

Table 11–H. *Exposure Standards for Radiofrequency and Microwave Radiation and Fields Where Access Cannot Be Controlled*

Part A: Electromagnetic Fields*

				Averaging Time (min)	
Frequency Range (MHz)	*Electric Field E (V/m)***	*Magnetic Field E (A/m)***	*Power Density, S (mW/cm²)*	*E², H²*	*S*
0.003–0.1	614	163	†	6	6
0.1–1.34	614	$16.3/f_m$	†	6	6
1.34–3.0	$823.8/f_m$	$16.3/f_m$	†	$f_m^2/0.3$	6
3.0–30	$823.8/f_m$	$16.3/f_m$	†	30	6
30–100	27.5	$158.3/f_m^{1.668}$	† †	30	$0.0636/f_m^{1.337}$
100–300	27.5	0.0729	0.2	30	—
300–3,000	—	—	$f_m/1,500$	30	—
3,000–15,000	—	—	$f_m/1,500$	$90,000/f_m$	—
15,000–300,000	—	—	10	$616,000/f_m^{1.2}$	—

Part B: Plane-Wave Equivalent Power Density Values

Frequency (MHz)	*E*	*H*
0.003–0.1	100	1,000,000
0.1–1.34	100	$10,000/f_m^2$
1.34–30	$180/f_m^2$	$10,000/f_m^2$
3.0–30	$180/f_m^2$	$10,000/f_m^2$
30–100	0.2	$940,000/f_m^{3.336}$

Part C: Induced and Contact Radiofrequency Currents

	Maximum Current (mA)		
Frequency Range (MHz)	*Through Both Feet*	*Through Each Foot*	*Contact*
0.003–0.1	$900f_m$	$450f_m$	$450f_m$
0.1–100	90	45	45

* The exposure values in terms of electric and magnetic field strength are obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).
** f_m = frequency in MHz.
† These plane-wave equivalent power density values, though not appropriate for near-field conditions, are commonly used as a convenient comparison with maximum permissible exposures at higher frequencies and are displayed on some instruments.
(From ANSI/IEEE C95.1-1991, 1992.)

tute (ANSI) adopted the 1991 revision in 1992. Hence, OSHA can enforce ANSI/IEEE C95.1-1991, so the reader should become acquainted with this standard (Figure 11–15).

MEASURING RADIOFREQUENCY RADIATION AND FIELDS

Recall that fields rather than radiation are presumed to exist at frequencies below 300 MHz so two surveys, one for electric fields and the other for magnetic fields, are needed. Only one survey is needed for frequencies above 300 MHz.

Electric fields at frequencies above 100 kHz are measured using small dipole antennas. The electric field induces a current in the dipole, which is connected to a diode. A diode is the electrical equivalent of a one-way valve so the induced current is allowed to leave the detector and goes to an amplifier. The amplified current drives a display. Alternatively, the electric field induces current flow and heating in an array of thermocouples and the change of resistance caused by heat-

Table 11–I. *Relaxations for Partial Body Exposures for Table 7 and 8* of the ANSI/ IEEE Standard*

	Frequency (GHz)	*Peak Value of Mean Squared Field*	*Equivalent Power Density (mW/cm²)*
Controlled Access Exposures	$0.001 \leq f_g < 0.3$	$<20E^2$ or $20 H^{2**}$	
	$0.3 < f_g \leq 6$		<20
	$6 < f_g \leq 96$		$<20 (f_g/6)^{1/4††}$
	$96 < f_g \leq 300$		40
Uncontrolled Access Exposures	$0.0001 \leq f_g \leq 0.3$	$<20 E^2$ or $20 H^{2†}$	
	$0.3 < f_g \leq 6$		4
	$6 < f_g \leq 30$		$f_g/1.5††$
	$30 < f_g \leq 300$		20

* These relaxations do not apply to the eyes and testes.
** E and H are spatially averaged values from Table 2 of the standard.
† E and H are spatially averaged values from Table 3 of the standard.
†† f_g in GHz.
(From ANSI/IEEE C95.1-1991, 1992.)

Figure 11–15. The internationally recognized radiofrequency hazard icon, "the radiator." OSHA has not updated its published radiofrequency standard, but has informed IEEE that it will not cite an organization using this symbol instead of the obsolete symbol found in the OSHA regulations.

ing is measured to drive the display. Dipoles and diodes can be used at lower frequencies (below about 100 kHz), but displacement sensors are also used.

Most dipole/diode field survey instruments gang three sensors together so they are mutually orthogonal (perpendicular to each other) to provide an isotropic response (a response that is about equal regardless of how the sensor is aligned in the field), as shown in Figure 11–16. Microwave oven survey instruments have two dipole/diode sensors that are perpendicular to each other. The lack of the third sensor makes them directional and they must be held so the probe handle is perpendicular to the surface being measured. When measuring electric fields using a single detector, it is often apparent where the field source is located so alignment of the detector is simple. A displacement sensor is oriented so that its flat surface faces the source; such an instrument is shown in Figure 11–17. Most instruments used for radiofrequency measurements below 300 MHz have displays marked to read in V/m. Instruments operating in the microwave region can be marked to read out in V^2/m^2 or mW/cm^2; microwave power density meters usually measure the electric field intensity and convert it to power density at the display.

Magnetic fields below 300 MHz are measured with single loops or triple mutually orthogonal loops. Single loops are highly directional, so the surveyor must follow the protocol outlined earlier in the section, measuring "Subradiofrequency Fields." Triple orthogonal loops are isotropic, so probe orientation is not critical.

Radiofrequency field and radiation measurements should be made where the worker would normally be, but without the person present, so reflections and induced fields do not create falsely high results. (This is similar to noise measurements, which are best done where the ears would normally be, but while the operator is away.) Either the sensor is held

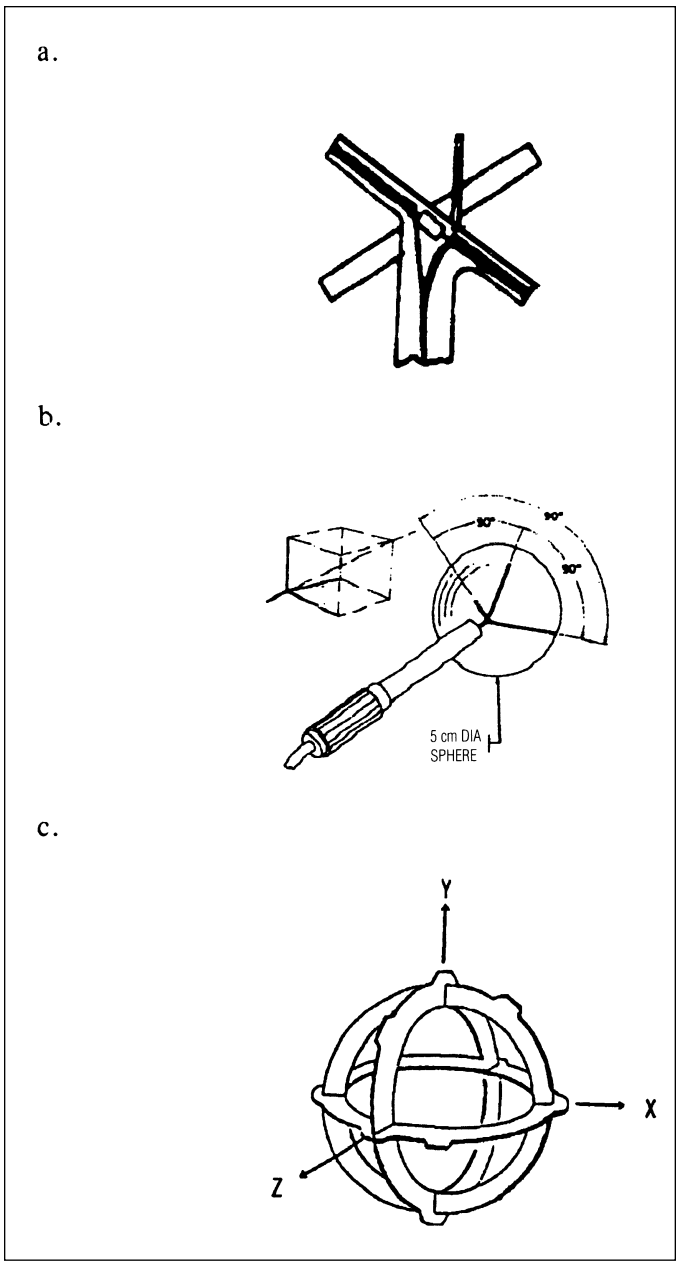


Figure 11–16. Isotropic (nondirectional) antenna arrays. a. Mutually orthogonal dipoles respond to electric fields (Holaday Industries HI 3102 probe). b. Mutually perpendicular array of thermocouples (Loral/Narda 8621 series probes). c. Mutually perpendicular magnetic field loops.

just above floor level and raised up through the body position at 8-in. (20-cm) vertical intervals and the result recorded for each point, or the probe is steadily moved through the body positions using an instrument with an add-on module that averages the readings. The sensor must be kept 20 cm or one sensor dimension (whichever is greater) from energized objects. At this time, measurements must be made at the locations of the eyes and testes. Exposures above the standard and their locations must also be recorded. Excursions up to 20 times the standard are allowed

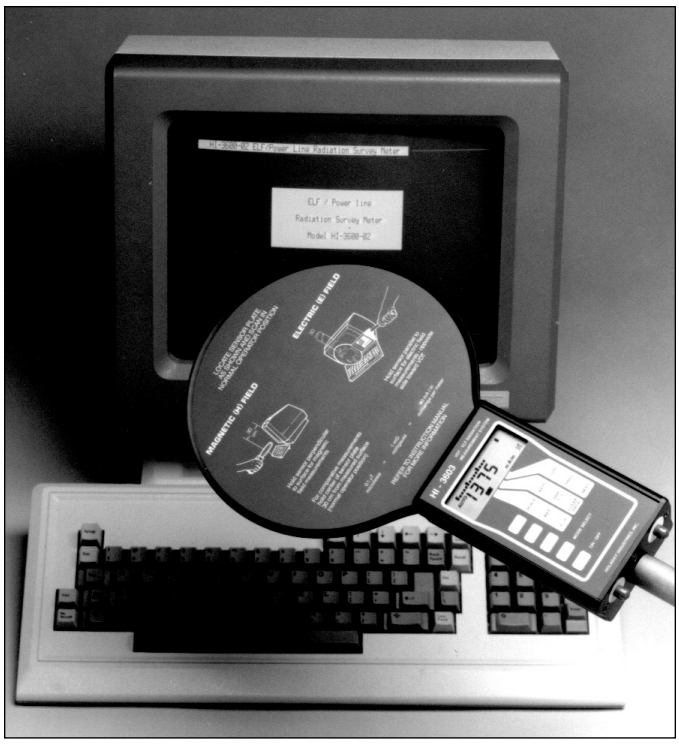


Figure 11–17. A displacement sensor is oriented so that its flat surface faces the source. (Courtesy Holaday Industries, Inc.)

at the extremities (hands and feet) and excursions up to 8 times the standards are allowed elsewhere (except at the locations of the eyes and testes).

Contact and induced current meters are now available. The contact current meter has electrodes that are pressed against an object that may be electrically charged due to ambient RF fields, as well as a cable and built-in ammeter. Induced current meters look like bathroom scales and are meant for people to stand on. The induced current flows through the instrument and drives an AC ammeter before going to ground. One manufacturer sells a cylindrical antenna that electrically simulates an upright human and can be placed on an induced current meter. Soon, an instrument that measures current flow through the ankle with a cuff-shaped coil will be available. At this time, ANSI/IEEE C95.1-1991 specifies that current flows are to be averaged over a 1-s time interval.

VIDEO DISPLAY TERMINALS AND MICROWAVE OVENS

Video Display Terminals

These are given their own section because they operate in both the ELF and VLF portions of the spectrum. A video display terminal (VDT) includes a cathode ray tube (CRT) very similar to the picture tube in a TV set. The CRT has an electron source or electron gun at the back and uses a high-voltage electric field to accelerate a beam of electrons from the gun to the screen and impart enough energy to the beam to cause phosphors on the inside of the screen to glow. The beam is steered to specific parts of the screen by a pair of fields created by magnets in a yoke near the back of the CRT. One magnetic field is aligned vertically the other horizontally. Remember that magnetic fields act at right angles. The vertical magnetic field moves the beam left and right while the horizontal field moves it up and down. The image on the screen contains about 500 lines (this varies with manufacturer) and it is refreshed or replaced with a brand-new image about 60 times a second (which also varies with manufacturer) to avoid flicker. Thus, the magnetic field that deflects the beam vertically has a frequency of about 60 Hz. The field that deflects the beam horizontally has a frequency of 60 images per second times the number of lines in the image (about 500), for about 30,000 Hz. The horizontal scanning field is generated by the "flyback" transformer. Most VDTs work at frequencies below 30,000 Hz, whereas a commercial TV image has 525 lines refreshed only 30 times a second, for a flyback frequency of 15.75 kHz. See Figure 11–18 for a depiction of the fields around a VDT or TV.

If you watched how the field strength of most VDTs changed with time, you would not see the familiar sine (ocean) wave. You would see the field slowly change as the beam was dragged from the left of the screen to the right, then abruptly change to the starting value so the beam could be swept across the next line (the beam itself is actually shut off during this abrupt reversal). The result is called a sawtooth waveform. The refresh field also has a sawtooth shape, but at a lower frequency.

Thus, a survey of VDTs is more complex than many other surveys. The electric and magnetic fields at two frequencies

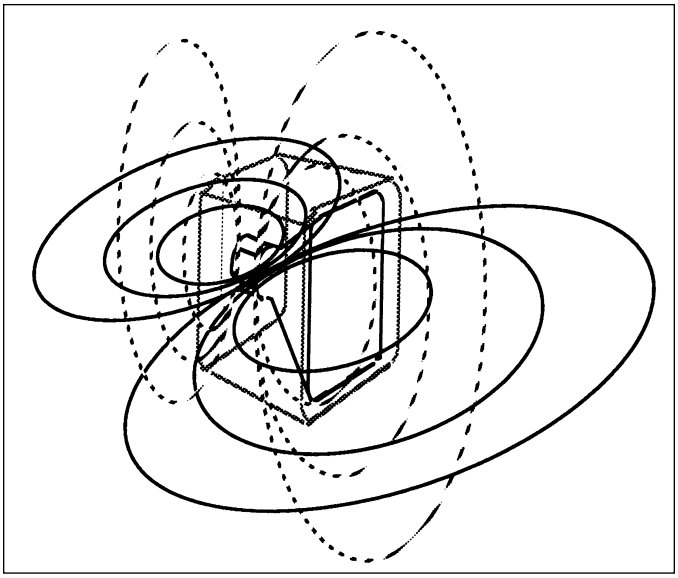


Figure 11–18. VDTs create two magnetic fields. The vertically aligned flyback field moves the beam horizontally at a frequency of 20,000–30,000 Hz. The horizontally aligned refresh field moves the beam from top to bottom at a frequency of about 60 Hz.

can be assessed. One manufacturer has developed a family of meters using paddle-shaped displacement electric field and single-loop magnetic field sensors for this application. A worker's electric field exposure is assessed by placing the sensor squarely over his or her chest so the electric field lines land on the sensor. Of course, the surveyor must stand away during electric field measurements (a fiber-optic remote readout is provided), but the surveyor can be near the VDT during magnetic field surveys.

The Swedish MPR or Swedish Board for Technical Accreditation (SWEDAC) standards are emission standards rather than exposure standards, and are summarized below:

ELF electric field	25 V/m
ELF magnetic field	2.5 mG
Electric field	2.5 V/m
Magnetic field	0.25 mG

The Swedish standard is given in two Swedish Board for Technical Accreditation publications cited in the Bibliography. It is a convenience standard; that is, it is based on what is attainable rather than on an estimate of what constitutes a safe exposure. SWEDAC wrote:

> *Knowledge of the biological effects of weak low-frequency magnetic fields is limited. The debate on this that occurred in Sweden during 1986 and 1987 resulted in the publishing of guidelines of acceptable values of fields from VDUs [video display units]. These guidelines were not based on biological effects, but rather on what was technically possible. The results obtained from the first three years of voluntary testing show that it is possible to obtain VDUs that give rise to only low magnetic field intensities without significantly degrading other performance requirements. It has also been found that, for good-quality VDUs, there does not appear to be any correlation between the magnetic field and the important visual ergonomic characteristics.*

SWEDAC specifies conducting a series of measurements at 50 cm in a laboratory with a controlled electromagnetic environment. Any field measurement made to assess approximate compliance with SWEDAC must be made at 50 cm rather than at the 30 cm customary in the United States. TCO, the Swedish Confederation of Professional Employees, has developed guidelines for VDT electromagnetic emissions and ergonomics. The TCO emission criteria are somewhat stricter than MPR's. TCO has established an office in Chicago to support distribution of its guidelines, which have been translated into English.

Microwave Ovens

Microwave ovens use the 2.45 GHz ISM band. Power is supplied by a magnetron tube and routed to the cooking chamber via a waveguide. The radiation leaving the waveguide passes over a rotor (or rotating waveguide) set in motion by moving air. The rotor is shaped to reflect the radiation around the cooking chamber to obtain a somewhat even distribution of energy. This caused concern when microwave ovens first appeared because the radiation leaking from an oven was amplitude-modulated by the rotor and could be picked up by cardiac pacemakers of that era. The pacemakers could amplify the leaking radiation rather than the heart's own electrical activity, with serious consequences for the user. Since that time, pacemaker manufacturers have added capacitors and protective circuits to block out extraneous fields and most pacemakers are now tested against electric fields equivalent to 10 mW/cm^2, the ANSI C95.1-1966 exposure standard in effect when microwave ovens first appeared. The present emission standard for microwave ovens, 21 *CFR* 1930.10, from the Food and Drug Administration, allows new ovens to leak no more than 1 mW/cm^2 when measured at 5 cm and old ovens to leak no more than 5 mW/cm^2 when measured at 5 cm (microwave oven survey meters have Styrofoam spacer cones to guarantee this 5-cm separation).

Excessive leakage from a microwave oven could occur if the oven was mechanically damaged, so oven users should check the condition of the door, door jamb, vision screen, and interlock when they use an oven and have damaged ovens repaired or replaced. Annual surveys are not warranted.

RF/MW CONTROLS

RF/MW shielding is relatively simple and can be installed using relatively inexpensive materials. Lead is not needed. The most effective form of shielding is applied at the source as an enclosure. Absorbing foams, porous polyurethane foam filled with carbon in a manner that causes the arriving radiation to pass through gradually lowering impedance, can be used. Electromagnetic radiation does not pass from one medium to another if the difference in electrical conductivities is large; it is simply reflected from the object. Air is a fairly good insulator, whereas metals are good conductors, so devices such as radar work by causing radiation arriving from air to strike and be reflected by metal. The foam manufacturer makes the impedance change gradually so the radiation is not reflected from the absorber. This can be done by forming the foam into pyramid shapes so the arriving radiation passes the tips and travels towards the bases of the pyramids. The impedance gradually drops as the radiation encounters less air and more carbon. The arriving radiation eases into the foam and induces a flow of electric current in the foam. Graphite is a poor conductor, so the current induced by the radiation is dissipated as heat. The foam manufacturer can also make the carbon content of the foam increase from nothing at the outside of the foam to a maximum level at the base of the foam. Then the foam can be sold as flat sheet because pyramids are not needed.

Metal screens or sheets also can be used for shielding or enclosures. The key concept is that the mesh openings be no more than 1/4 wavelength in dimension. Metal screens and sheets must be electrically bonded to each other where they join and the whole assembly grounded; otherwise, fields can pass through the gaps. A Faraday cage is a grounded enclosure made of continuously bonded conductors. An object inside is protected from electric fields and radiation on the outside. The doors and door jambs of Faraday cages are lined with resilient alloy strips that make contact when the door is shut so the door is bonded to the jamb and the rest of the cage.

Waveguides and coaxial cables are used to transfer power and act as enclosures. Waveguides are open metallic conduits with flanged ends. The flanged ends allow waveguides to be fastened to other waveguides, sources, or receivers. Waveguides must be snugly attached or leakage will occur. Similarly, coaxial cables can be bent and fail. Leakage can occur where they fail.

Copper tape is most commonly used in electrical engineering. It is used to patch leak points in enclosures or in runs of waveguide. Very-high–power devices have been successfully enclosed in wooden boxes lined on the inside with well-joined copper sheets and absorbing foam and finished outside with copper tape at the seams.

Distance is very effective in far fields, due to the inverse square law, and also can be used in near fields. Examples of using distance as a control include enclosing a source in a barricade to keep people away from the source or using long-handled tools to manipulate objects immersed in strong radiation fields.

Time limitations are possible, based on a 6-min averaging time, but often are not practical. Another control, the sign found in the OSHA nonionizing radiation standard, became obsolete in 1992; the symbol shown in Figure 11–15 should be used instead of the aluminum, black, and red diamond found in the old OSHA standard. The magenta and yellow trefoil associated with ionizing radiation should never be used!

OPTICAL RADIATION AND LASERS

CIE Bands

Optical radiation includes infrared/visible and ultraviolet radiation. Optical radiation is manipulated with nonconductive optics (with the exception of mirrors, which use metal to reflect the radiation). It is customary to describe optical radiation by wavelength rather than frequency. Nomenclature has been developed by the Commission Internationale d'Eclairage (CIE), or International Lighting Commission. The band designations for infrared and ultraviolet radiation begin at the border of each band starting with visible radiation (wavelength of 400–750 nm) and extend each way from the visible band:

CIE Band	*Wavelength*	*Non-CIE Nomenclature*
Microwaves	>1 mm	
IR-C	3 μm–1 mm	Far IR: 25 μm–1 mm
IR-B	1.4 μm–3 μm	Intermediate IR: 2500 nm–25 μm
IR-A	760–1400 nm	Near IR: 760–2500 nm
Visible	400–760 nm	
UV-A	315–400 nm	Near UV, black light
UV-B	280–315 nm	Middle UV, actinic UV
UV-C	100–280 nm	Far UV, actinic UV, Vacuum UV: <200 nm
x rays	<4 nm	

Note that the ANSI standard for laser safety, Z136.1-1993, uses the non-CIE terms *near*, *intermediate*, and *far* to define IR bands.

BIOLOGICAL EFFECTS AND EXPOSURE STANDARDS FOR OPTICAL RADIATION

Biological effects of optical radiation result from thermal and photochemical mechanisms. (The scientific controversy and uncertainty that plague efforts to protect people from microwave, RF, and ELF do not apply to optical radiation.) Thermal effects are dominant in the IR portion of the spectrum, photochemical effects dominate in the UV, thermal effects are more important at the red end of the visible spectrum, and photochemical effects are dominant at the blue end of the visible spectrum. The target organs are the eyes and skin. Visible and IR-A radiation, 400–1400 nm, is particularly hazardous to the eye because it is transmitted through the cornea, is focused by the lens, and strikes the retina. The potential for retinal damage is great because the radiation can be highly concentrated by focusing.

The Eye

The exterior of the eye is protected by a transparent layer that contains living tissue, the cornea. The cornea is wetted by continual blinking of the eyelids when they are open. The vitreous humor, a sac of watery material, lies inside the cornea. The cornea and vitreous humor form the anterior portion of the eye, which is divided from the posterior region by the iris, which is opaque and pigmented. The iris can absorb energy and be heated by radiation. The iris contains muscles that adjust the size of the central opening, the pupil, to control the amount of light passing into the rest of the eye. Behind the iris lies the lens, a flexible mass that is made thicker or thinner by the ciliary muscles to provide the sharpest possible image on the retina. It transmits visible and IR-A radiation, but other bands of IR and UV are absorbed here or at the cornea. Light passes through the aqueous humor and strikes the retina, where photosensitive cells convert the energy of light to electrical signals that are fed to the vision centers of the brain and the pineal. There are two types of photoreceptor cells in the retina: rods, which work in a broad range of lighting conditions but cannot differen-

tiate between wavelengths (see colors), and cones, which perceive colors in brightly lit conditions. Rods cover the entire retina, but cones cover only the macula, a small area in the back of the retina. The fovea, a small pit rich in cones and essentially rod-free, is located in the center of the macula directly opposite the center of the iris, which makes color vision particularly vulnerable to overexposures to visible and IR-A radiation. When the lens is removed surgically, creating an aphakic condition, then UV-A that normally is blocked by the lens also passes through and evokes a retinal response. The rods lie on a bed of highly pigmented tissue, the retinal pigmented epithelium (RPE); whereas the rods are essentially transparent and do not absorb light, the underlying RPE can absorb light, become hot, and damage the rods. (See Chapter 5, The Eyes, for anatomical illustrations of the human eye.)

The target portions of the eye are summarized below:

CIE Band	*Wavelengths*	*Primary Visual Hazard*	*Other Visual Hazards*
IR-C	1 mm–3.0 μm	Corneal burns	
IR-B	3 μm–1.4 μm	Corneal burns	
IR-A	760–1400 nm	Retinal burns	Cataracts of lens (glassblowers' cataracts)
Visible	400–760 nm	Retinal burns	Night and color vision impairment (chronic exposures to intense sunlight)
UV-A	315–400 nm	Cataracts of lens	
UV-B	280–315 nm	Corneal injuries (welder's flash)	Cataracts of lens (at longer wavelengths of UV-B band)
UV-C	100–280 nm	Corneal injuries (welder's flash)	

See Figure 11–19 for a summary of the CIE bands and target organs of optical radiation.

The blood circulating through the choroid below the retina is an important defense mechanism. The capillaries in the choroid have larger diameters than typical capillaries elsewhere, but the oxygen demand of the living retinal and other eye tissues is modest; this capillary net is a vast liquid cooling system that extracts heat from the retina. This defense can be overwhelmed by an extremely brief but intense pulse of light into the retina providing energy above the rate at which the heat can be extracted by blood flow. Pulsed lasers are particularly hazardous; they can deposit energy so rapidly that the water in the retinal tissue flashes to a boil and "explodes," causing local tissue damage. If the same amount of energy is deposited in a shorter time period in briefer pulses, more damage is created by the shorter pulses because less heat dissipation can occur. This thermoacoustic mechanism of damage was unknown until the laser was invented. Alternatively, large quantities of light can be hazardous when deposited over larger areas of the retina; this is why it is unsafe to look at the sun through a telescope. The choroid circulation can remove the heat of glimpsing at the sun for a brief period because the image of the sun on the retina is so small that only a small part of the retina is strongly illuminated. A telescope makes the retinal image much larger and the brightness that was limited to just a small retinal area now strikes a much larger area. This can overwhelm the heat-removing capacity of choroid circulation. Visible radiation can cause retinal injuries or burns because it is transmitted and focused. If the resulting lesion, or scotoma, damages some portion of most of the retina, very little visual impairment will result, but if the scotoma occurs in the macula, serious visual impairment results.

Another defense is afforded by aversion reflex actions such as blinking or looking away from bright light. Excessively bright light prompts these responses, which end exposure in about 1/4 s; this is enough to provide protection from injuries due to sunlight and most artificial light sources other than lasers. One reason why lasers are hazardous is because they can deposit damaging amounts of energy into the eye well before the aversion reflex ends the exposure.

The Skin

See Chapter 3, The Skin and Occupational Dermatoses, for anatomical illustrations of the skin. The outermost layer of skin, the epidermis, contains a single sheet of cells at its base, consisting of keratinocytes (cells that divide and move outward) and melanocytes (cells that form dark granules of melanin pigment that are transferred to the keratinocytes). The keratinocytes divide and are pushed outward by newer cells being created by the basal cells. As they move outward they flatten, develop pigment granules, and finally die. Thus, the dividing and moving keratinocytes carry pigment with them. This pigment absorbs UV and prevents the generation of excessive levels of vitamin D and UV injuries to the dermal and subcutaneous tissues below. The inner layer of living cells is called the stratum malphigii; the outermost layer of dead cells the stratum corneum.

IR and visible light skin injuries are confined to thermal burns. About 2/3 mW/cm^2 irradiance produces a feeling of warmth. UV also causes skin effects through photochemical mechanisms. Sunbathers now use sunscreen lotions to allow UV-A to reach the skin and stimulate melanin production by the melanocytes, but absorb UV-B before it can reach the skin. UV-B and UV-C produce two undesirable effects: the skin toughening evident among desert dwellers and skin cancer. (Outdoor exposures do not include UV-C because it is absorbed by oxygen in the atmosphere to produce ozone.) Research now shows that UV-A can also cause skin cancer. Thermal and photochemical damage mechanisms again dominate. The most common skin effect is erythema, or reddening, which is commonly called sunburn. UV penetrates to the living cells of the dermis and causes damage, which is

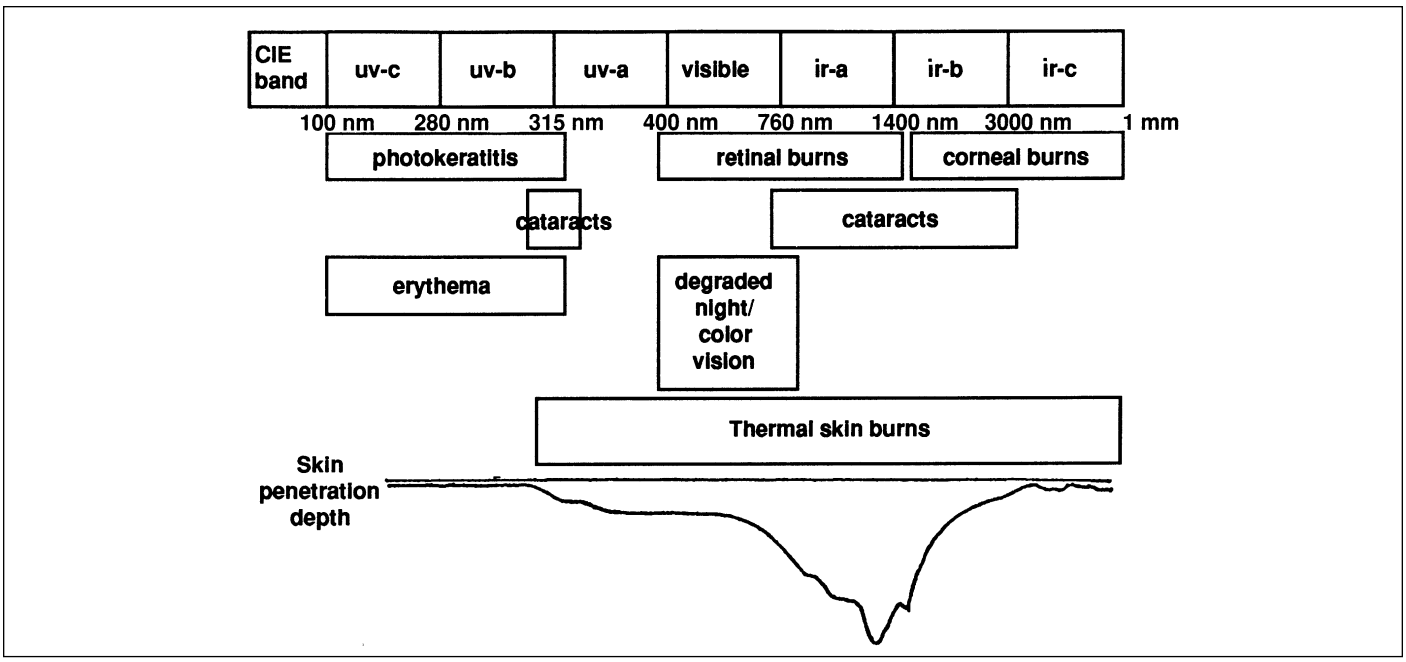


Figure 11–19. A summary of the CIE bands and target organs for the various types of radiation. (From Sliney & Wolbarsht, 1985.)

repaired. Blood supply to the skin is increased as part of the repair process, causing the reddening. Repeated exposure to UV, particularly UV-B, causes the skin to thicken and harden. This is why people who live in sunny areas can develop leathery skin.

The exposure standards that address UV and far IR exposure to the skin are about the same as the standards addressing eye exposures, but the standards for visible and near IR skin exposure are much more lenient than those for eye exposure because of the possibility of retinal damage caused by focusing.

Standards

It is necessary to digress into mathematics here. Optical radiation and laser safety standards use *radians* rather than degrees as a measure of angle. The length of an arc (segment of a circle) created (subtended) by a given angle is equal to the radius of the circle times the size of the angle in radians. Put another way, the size of a source that is emitting radiation or a surface that is reflecting radiation is equal to the distance between the source or surface and the viewer times the angle in radians. The customary symbol for the angle is alpha (α). The use of radian units is shown in Figure 11–20. For comparison purposes, half a circle, 180°, is π (about 3.1416) radians and a full circle, 360°, contains 2π (about 6.2832) radians. Another angular measure is also used to describe portions of the surface of a sphere: the *steradian*. Radians and degrees cover familiar two-dimensional circles and arcs, but the steradian unit applies to three-dimensional situations such as areas that are reflecting or generating radiation. The size of an area on the surface of a sphere is equal to the solid angle subtended by that area times the radius of the sphere. A sphere subtends a solid angle of 4π steradians. Put another way, the size of an illuminated or radiating area is equal to the square of the distance between the area and the observer times the solid angle, in steradians.

The principal standards for nonlaser optical radiation are found in the back of the TLV® booklets issued annually by the ACGIH. ACGIH groups visible radiation with IR radiation and addresses UV separately. These TLVs are fundamentally identical in concept to the more familiar noise

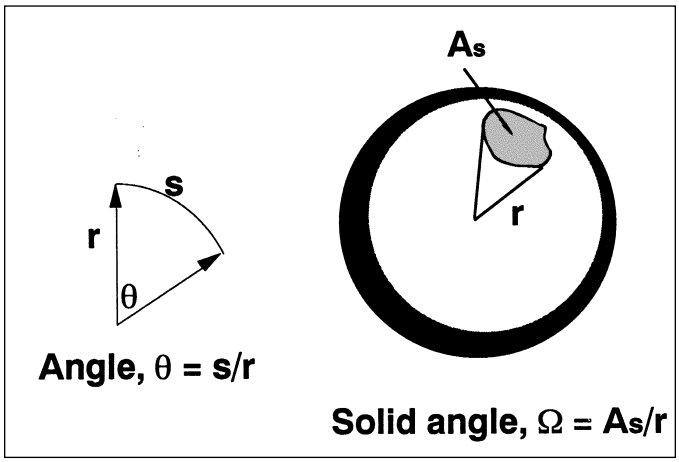


Figure 11–20. An angle in radians can be calculated by dividing its arc by the radius. A solid angle can be calculated in steradians by dividing the area subtended by the solid angle by the radius squared. In optical safety applications, the arc is the long dimension of an illuminated or luminous area. The area for a solid angle calculation is the illuminated or luminous area. In both cases, the radius is the distance between the illuminated or luminous area and an observer.

standard in that they use spectral effectiveness factors to account for the difference in damage caused by energy of different wavelengths (much as the A-weighting curve does for noise exposures) and they trade exposure intensity off against permissible exposure time. Instruments are now on the market that have wavelength response characteristics that approximate the spectral effectiveness curves of the TLV®s; such an instrument is shown in Figure 11–21.

The TLV for visible/IR radiation has two basic elements: one for situations where visible radiation is present and a much simpler standard that applies when only IR is present. The visible standards must account for both photochemical injuries at the blue end and thermal injuries at the red end and IR. The thermal injury standard covers wavelengths from 400 to 1,400 nm and balances ambient irradiances multiplied by the appropriate spectral effectiveness factors (listed in a table that shows that the maximum thermal hazard exists almost at the UV end, wavelength = 435 and 440 nm) against the angle being viewed and the exposure time. Thus, stronger exposures to more hazardous wavelengths from bigger sources warrant shorter permissible exposures. The TLV also specifies making a second comparison to account for blue light photochemical hazards of visible radiation, wavelengths from 400 to 700 nm. A table of spectral effectiveness factors is given for red light and blue light injury. Stronger exposures of more hazardous wavelengths from bigger sources (sources covering larger solid angles) are balanced against permissible exposure duration. Special spectral effectiveness factors are required for those who have had their lenses removed (aphakes); these require assessments down to 305 nm (through all of UV-A and just into the high wavelength end of UV-B).

The IR TLV does not extend to wavelengths >1.4 μm; one must consult LIA/ANSI laser safety standard Z136.1 for guidance about wavelengths between 1.4 μm and 1 mm. The Z136 standard can be applied to nonlaser sources at wavelengths above 1.4 μm because the concern about retinal focusing does not exist above 1.4 μm so eye and skin hazards are the same for laser and nonlaser sources.

Two formulas are given for situations such as heat lamps where IR is not accompanied by visible radiation. One formula addresses corneal hazards from 770 nm to 3 μm by limiting exposure times if irradiances exceed those allowed for viewing intervals greater than 1,000 seconds (10 mW/cm^2). The other addresses retinal hazards from 770 to 1400 nm.

The TLV for UV uses similar logic and relies on a combined eye and skin hazard weighting curve so only one set of measurements is needed. The combined curve shows maximum potency at 270 nm. Neither the skin nor the eye hazard curve peaks at 270 nm, but the combined curve does. Instruments have been developed in which the sensor *response* approximates the combined UV spectral effectiveness curve.

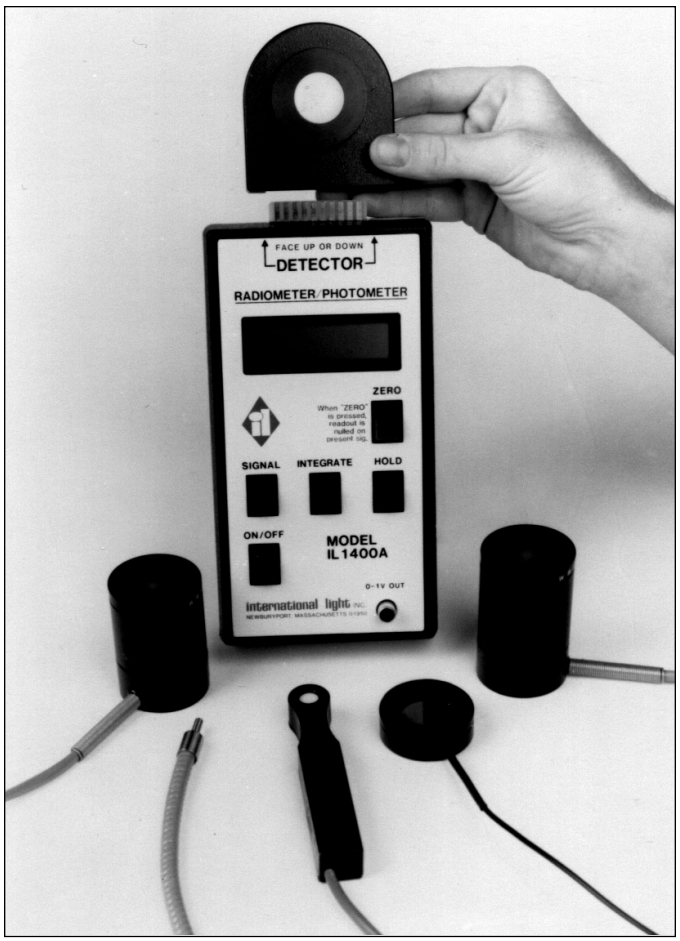


Figure 11–21. Instruments are now on the market that have wavelength response characteristics that approximate the spectral effectiveness curves of the TLVs. (Courtesy International Light, Inc.)

Controls for Nonlaser Sources

It is necessary to discuss optical density before proceeding to controls. *Optical density* (OD) is the base-10 logarithm of the ratio of the intensity of the radiation leaving the filter divided by the intensity of the radiation entering the filter (the attenuation provided by the filter). If a filter absorbs all but 1 percent, or 1/100, of the radiation entering it, then the OD is the logarithm of 100, or 2. If a (1-kW) laser beam strikes a filter and only 1 mW is transmitted through the filter, then the filter reduced the beam intensity by a factor of 1,000,000 and its OD is 6.

A variation of optical density, *shade number*, has been used in ANSI Z49.1 to describe welders' eye protection for several decades. The shade number is 1 plus the product of 7/3 multiplied by the optical density of the filter.

Baffles and sight barriers are common engineering controls for optical radiation, particularly for welding areas. A number of vendors sell absorbing plastic panels that allow observers to see welders without being exposed to hazards from arcs.

Table 11–J. ***Guide for Welding Shade Numbers***

Process	*Electrode Size in 1/32 in. (mm) or Process Description*	*Arc Current (A)*	*Minimum Protective Shade***	*Suggested Shade (Comfort)**
Shielded metal arc	<3 (2.5)	<60	7	—
	3–5 (2.5–4)	60–160	8	10
	5–8 (4–6.4)	160–250	10	12
	>8 (6.4)	250–550	11	14
Gas metal arc or flux covered arc		<60	7	—
		60–160	10	11
		160–250	10	12
		250–550	10	14
Gas tungsten arc		<50	8	10
		50–150	8	12
		150–500	10	14
Air carbon	Light	<500	10	12
Arc cutting	Heavy	500–1,000	11	14
Plasma arc welding		<20	6	6–8
		20–100	8	10
		100–400	10	12
		400–800	11	14
Plasma arc cutting	Light†	<300	8	9
	Medium†	300–400	9	12
	Heavy†	400–800	10	14
Torch brazing				3** or 4
Torch soldering				2
Carbon arc welding				14
		Plate thickness in. (mm)		
Gas welding	Light	<1/8 (<3.2)		4** or 5
	Medium	1/8-1/2 (3.2–12.7)		5** or 6
	Heavy	>1/2 (>12.7)		6** or 8
Oxygen cutting	Light	<1 (<25)		3** or 4
	Medium	1-6 (25–150)		4** or 5
	Heavy	>6 (>150)		5** or 6

* Start with a shade too dark to see the weld zone. Then go to a lighter shade that gives a sufficient view of the weld zone without going below the minimum. In oxyfuel gas welding or cutting, where the torch produces a harsh yellow light, use a filter lens that absorbs the yellow or sodium line in the visible radiation.
** This is listed as the minimum protective shade in the OSHA General Industry Standard for Eye and Face Protection, 29 *CFR* 1910.133 of April 6, 1994.
† These values apply where the arc can be seen clearly. Experience has shown that lighter filters can be used when the arc is hidden by the workpiece.
(From AWS/ANSI Z49.1-1988.)

A wide variety of personal protective equipment is now available for nonlaser optical radiation hazards. Some points of interest follow:

- ➢ The shade numbers for welding eyewear are summarized in Table 11–J. They are excerpted from ANSI Z49.1-1988, which OSHA incorporated in the 1994 revisions of 29 *CFR* Subpart I, personal protective equipment standards.
- ➢ Common glass does not offer complete protection against UV-A, although it is very effective against UV-B and UV-C. Tinted eyewear is often effective against UV-A. Eyewear vendors will send transmission curves for their products that can be used to select UV-A protective eyewear for applications that do not involve intense exposures to UV-A.
- ➢ The use of photochemically darkened lenses should be avoided because the lenses can darken fairly rapidly in response to sunlight, but become paler slowly. One can enter a building or drive into a tunnel and experience impairment of vision by such glasses, particularly immediately after entry, until the tinting adjusts to the reduced light levels.
- ➢ Special lenses are available for nonlaser light and IR sources such as glass blowing and steel making.
- ➢ OSHA standard 29 *CFR* 1910.133 requires eye and face protectors to be distinctly marked to facilitate identification of the manufacturer and to meet ANSI Z87.1-1989 impact criteria. OSHA standard 29 *CFR* 1910.133 also requires that protective eyewear for users with prescriptions either have the prescription built in or be worn over prescription lenses without disturbing the prescription lenses. Several eyewear vendors now offer clip-on adapters so prescription lenses can be worn behind eyewear that filters optical radiation.

LASER

Laser is an acronym for *light amplification by stimulated emission of radiation.* Its original derivation has been obscured by

years of common use. The original lasers followed microwave devices called masers (the *m* stands for *microwave*) and were called optical masers. Masers and lasers work by pumping the electrons in a suitable material, the lasing medium, with strong energy and directing some of that energy out in the form of a beam of radiation. To do this, most lasers include the parts shown in Figure 11–22: a source of pumping energy such as a flash lamp or electrodes embedded in a gas-filled tube, a lasing medium that emits radiation when pumped, and a resonant cavity that is a multiple of the product radiation's wavelength and is formed by placing a mirror at each end of the lasing material. The pumping energy strikes electrons of atoms in the lasing medium, which quickly lose the pumping energy as radiation. Some of the radiation produced hits electrons in other pumped atoms in the lasing medium and makes them yield their stored energy as more radiation. The radiation reaches one end of the cavity and is reflected off of a mirror back into the lasing medium, where it strikes more electrons in other pumped atoms and causes them to yield their energy until it strikes a mirror at the opposite end of the cavity, where the process begins again. The radiation surges back and forth along the cavity, gaining strength until it emerges from one end (with a partially reflective mirror) as a beam with parallel sides.

Laser radiation has unique properties. It is monochromatic, which means that it is made of one or a few wavelengths of radiation, determined by the lasing material. It is coherent; that is, the waves are matched to one another as soldiers in a column are matched to one another. It is also bright. It can have very high irradiance and be focused to deposit intense energy on small surfaces. Coherent radiation can be very sharply focused whereas common noncoherent radiation cannot. The parallel-sided and coherent nature of the product radiation means that the beam does not spread as rapidly as radiation from other sources. Thus, a laser beam keeps its strength over long distances. Visible and IR-A laser beams can be focused to create extremely intense exposures on the retina that deliver up to 300,000 times as much power or energy per unit area on the retina as on the outside of the eye. This is why laser safety standards are much stricter in this band than at other bands and why laser standards are stricter than standards for noncoherent sources in this band.

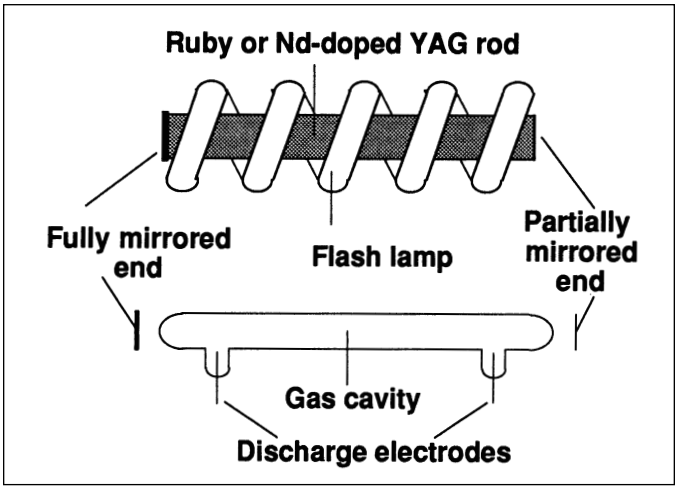


Figure 11–22. Parts of two types of lasers: solid state and gas. The top drawing is a solid-state laser, the bottom a gas laser. Both lasers fit in protective housings that include cooling equipment for high-power lasers and a beam-blocking device for Class 4 lasers. Power supplies and control panels are usually located elsewhere; the power supply and cooling cables leading to the laser enclosure give a rough indication of the laser's power.

Lasers can be operated in two major modes, much like other radiation sources: pulsed and continuous wave (CW). Exposure standards and laser outputs for pulsed and relatively brief exposures are expressed in J/cm^2 of lit area; exposure standards and outputs for continuous wave lasers are expressed in W/cm^2 of lit area.

All forms of matter are used as lasing media. The first lasers used ruby rods; the pumping energy came from high-intensity flash lamps. Yttrium aluminum garnets treated with neodymium (Nd-doped YAG) followed for IR-A lasers. Helium-neon (He-Ne) lasers, essentially neon lamps filled with helium-neon mixtures surrounded by mirrors to create an appropriate resonant cavity, are very common. Similar lamps filled with krypton, argon, or carbon dioxide gas are also in common use. Carbon dioxide lasers produce 10.6 μm beams in the IR-C band; the other lasing media just mentioned produce mostly visible wavelengths, as shown in Tables 11–K and 11–L. Organic dyes are used because the output wavelength can be precisely adjusted at the discretion of the user, unlike other media, which have fixed product wavelengths. Solid-state diodes made from selectively blended compounds of gallium arsenide can be used to produce radiation in the IR-A band and diode lasers are now used in supermarket bar code scanners and lecture hall pointers. Diode lasers producing dangerous outputs can be smaller than a fingertip. Excimer lasers use ionized halogen atoms in inert gases to emit UV radiation.

Energy sources usually use electricity to fire flash lamps or energize electrodes in a gas cavity, but other forms of pumping energy can be used. The energy released by the combustion of deuterium and fluorine is harnessed in gas dynamic lasers, rocket engine-like devices that exhaust in one direction and produce an IR beam in a perpendicular direction. Dye lasers use light from a flash lamp or from another laser for pumping.

Biological Damage Mechanisms of Lasers

Laser beams produce biological damage by the two mechanisms mentioned earlier (thermal burns and photochemical injuries) and visible and IR-A lasers produce retinal damage by a third mechanism unique to lasers. The highly focused beam generates a steam bubble near the retina that pops,

Table 11–K. *Common Continuous Wave Laser and Division into Classes by Accessible Emission Limits**

Lasing Medium	*Output Wavelength (nm)*	*Class 1 (W)*	*Class 2 (W)*	*Class 3b (W)*	*Class 4 (W)*
UV-B and C					
Argon	275	$\leq 9.6 \times 10^{-9}$ for 8 h	—	>Class I and <0.5	>0.5
UV-A					
Helium-cadmium	325				
Argon	351 and 363	$\leq 3.2 \times 10^{-6}$	—	>Class I and <0.5	>0.5
Krypton	350.7 and 356.4				
Visible					
Helium-cadmium	441.6				
Argon	457, 476, 488, 514, etc.				
Krypton	530				
Neodymium: YAG first harmonic	532	$\leq 0.4 \times 10^{-6}$			
Helium-neon	543				
Dyes	400–550		>Class I, but 1×10^{-3}	>Class I and <0.5	>0.5
Helium-selenium	460–550				
Helium-neon	632	$\leq 7 \times 10^{-6}$			
Dyes	550–700	$<0.4 \times 10^{-6}$ to 7×10^{-6}			
Indium gallium aluminum phosphide	670	$\leq 2.4 \times 10^{-5}$			
Titanium-sapphire	670	$\leq 2.4 \times 10^{-5}$			
Krypton	647, 676.4	1.1×10^{-5}, 3×10^{-5}			
Near IR					
Gallium aluminum arsenide	780	$\leq 0.18 \times 10^{-3}$			
As above	850	$\leq 0.25 \times 10^{-3}$			
Gallium arsenide	905	$\leq 0.32 \times 10^{-3}$	—	>Class I and <0.5	>0.5
Neodymium-YAG	1.064 μm	$\leq 0.64 \times 10^{-3}$			
Helium-neon	1.080 and 1.152 μm only	$\leq 0.64 \times 10^{-3}$			
Indium gallium arsenic phosphide	1.310 μm	$\leq 4.40 \times 10^{-3}$			
Far IR					
Indium gallium arsenic phosphide	1.550 μm				
Holmium	2.10 μm				
Erbium	2.94 μm				
Hydrogen fluoride	2.6–3 μm	$\leq 9.6 \times 10^{-3}$			
Helium-neon	3.39 μm only		—	>Class I and <0.5	>0.5
Carbon monoxide	5.00–5.50 μm				
Carbon dioxide	10.6 μm				
Water vapor	118	$\leq 9.5 \times 10^{-2}$			
Hydrogen cyanide	337				

* Assumes no mechanical or electrical design incorporated into laser system to present exposures from lasting 8 hours; otherwise, the Class 1 AEL could be larger than tabulated.
(From LIA/ANSI Z136.1-1993.)

sending shock waves into the retinal tissue that produce thermoacoustic tissue damage. Briefer pulses are more hazardous than longer pulses of equal energy content because the heat does not dissipate as much during a shorter pulse. Q- switching is a method of reducing the pulse duration of a laser. Q-switched pulses can last tenths of microseconds whereas the original unswitched beams can last milliseconds. Thus, joule for joule, Q-switched pulses are more hazardous than non-Q-switched pulses. The bursting bubble can damage blood vessels and blood is toxic to nerve tissue, so the degree of lasting impairment caused by thermoacoustic injury is a matter of luck determined by what part of the retina was struck and whether blood reached nerve tissue.

It is important to note that coherent visible and IR-A radiation with wavelengths of 400–1,400 nm can be focused into an ultra-small (diffraction-limited) spot at the back of the retina. The brightness of the radiation striking the retina can be as much as 300,000 times stronger than that entering the eye. Thus, visible and IR-A lasers are particularly hazardous to the eye. This explains why laser exposure standards are so strict.

Standards

The dominant standard for laser safety in the United States is the Laser Institute of America's LIA/ANSI Z136.1 standard, *American National Standard for Safe Use of Lasers*, last revised in 1993. Regulations for commercial laser products promulgated by the Center for Devices and Radiological Health (CDRH) of the Food and Drug Administration, 21 *CFR* Part 1040, are important for commercial laser devices.

The ANSI standard addresses facility and program elements as well as laser safety features. The 21 *CFR* 1040

Table 11–L. *Common Single-Pulsed Lasers and Division into Classes by Accessible Emission Limits*

Lasing Medium	*Output Wavelength (nm)*	*Pulse Duration*	*Class 1 (J)*	*Class 3b (J)*	*Class 4 (W)*
UV					
Argon fluoride excimer	193	20 ns	$\leq 1.9 \times 10^{-6}$		
Krypton fluoride excimer	248	20 ns	$\leq 1.9 \times 10^{-6}$		
Xenon chloride excimer	308	20 ns	$\leq 4.3 \times 10^{-6}$	>Class 1, but <0.125	>0.125
Nitrogen	337	10 ns	$\leq 3.6 \times 10^{-6}$		
Xenon fluoride excimer	351	20 ns	$\leq 4.3 \times 10^{-6}$		
Visible					
Rhodamine 6G dye	450–650	1 μs	$\leq 0.2 \times 10^{-6}$	>Class 1, but <0.03 C_A*	
Copper vapor	510 and 578	25 ns	$\leq 2 \times 10^{-7}$		
Neodymium–YAG, 1st harmonic	532	20 ns**	$\leq 2 \times 10^{-7}$	>Class 1,* but ≤0.03 C_A	>0.03
Ruby (Q-switched)	694.3	20 ns	$\leq 0.2 \times 10^{-6}$		
Ruby	694.3	1 ms	$\leq 4 \times 10^{-6}$		
Near IR					
Titanium sapphire	700–1,000	6 μs	$\leq 1.9–7.7 \times 10^{-7}$	Class 1, but ≤0.03	>0.03
Alexandrite	720–800	100 μs	$\leq 0.76–1.1 \times 10^{-6}$		
Neodymium–YAG (Q-switched)	1.064 μm	20 ns**	$\leq 2 \times 10^{-6}$	>Class 1, but ≤0.15	>0.15
Far IR					
Erbium–glass	1.54 μm	10 ns*	$\leq 9.7 \times 10^{-2}$		
Cobalt–magnesium fluoride	1.75–2.50 μm	80 μs	$\leq 97–9.7 \times 10^{-3}$		
Holmium	2.10 μm	0.25 ms	$\leq 9.7 \times 10^{-3}$		
Hydrogen fluoride	2.60–3.00 μm	400 ns	$\leq 1.1–0.11 \times 10^{-3}$	>Class 1, but ≤0.125	>0.125
Erbium	2.94 μm	0.25 ms	$\leq 6.8 \times 10^{-3}$		
Carbon dioxide	10.6 μm	100 ns**	$\leq 9.7 \times 10^{-4}$		
Carbon dioxide	10.6 μm	1 ms	$\leq 9.6 \times 10^{-3}$		

* See Table 11–P for the definition of C_A.
** Q-switched.
(From LIA/ANSI Z136.1-1993.)

addresses product safety features. Both standards were early uses of the hazard control class type of regulation. Control class regulations require assigning a classification that reflects the severity of the hazard. For lasers, the principal parameters that describe the anticipated hazard severity are wavelength and output power or energy.

Other measures of anticipated severity are pulse duration and the size of extended sources such as groups of diode lasers or the reflection of a spread laser beam from a surface. The LIA/ANSI and CDRH standards specify precautions based on the anticipated hazard of the accessible beam by setting accessible emission limits (AELs) for the amount of laser energy people could encounter from each class of laser. Precautions can be relaxed when the beam is thoroughly enclosed or reduced in power before it can enter a place where people could be exposed to it; this gives laser equipment suppliers a strong incentive to apply effective engineering controls. Precautions become more stringent in a series of defined steps (Classes) as the output of the laser increases from Class 1 (so low-powered as to be intrinsically safe) through Class 4 (very dangerous).

Classifications for several lasers are given in Tables 11–K and 11–L. Extremely weak beams are deemed nonhazardous (Class 1) and no precautions are needed. Low-power visible beams that could be hazardous if viewed for prolonged periods (Class 2 and 2a) warrant limited precautions. Class 2a visible lasers are those that could cause excessive exposures if the beam was viewed for 1,000 s or more; Class 2 lasers are visible light lasers that could produce excessive exposures if viewed for more than the 0.25-s response time of the aversion reflexes. Class 3 moderate-power lasers warrant more precautions and include moderately high-powered visible lasers and moderately powered invisible UV and IR lasers. Class 3 lasers are subdivided into Class 3a and 3b; Class 3a includes lasers that could be hazardous only if stared at or viewed through an optical device such as a telescope. All other Class 3 lasers are Class 3b and are presumed to have beams powerful enough to harm the eye during incidental exposure without an optical instrument. Class 4 high-power lasers warrant rigorous precautions because the beam can harm the skin and eyes and even diffuse reflections could be harmful. The precautions specified by LIA/ANSI Z136.1-1993 for each class are summarized in Table 11–M.

The use of hazard control classes reduces the need for measurements to determine personnel exposures and puts reliance on being able to estimate exposures by calculations.

LIA/ANSI Z136.1-1993 also sets maximum permissible exposures (MPEs) for lasers, as listed in Tables 11–N, 11–O, and 11–P. The MPEs are directly equivalent to OSHA PELs for chemicals or the MPEs for radiofrequency/microwave radiation set by ANSI/IEEE C95.1-1991. Adjustment factors are applied to calculate MPEs for extended sources,

Table 11–M. *Summary of Principal Laser Hazard Control Measures*

	Laser Class					
Control Measure	***1***	***2a***	***2***	***3a***	***3b***	***4***
Engineering Controls						
Protective housing	Shall	Shall	Shall	Shall	Shall	Shall
Without protective housing	LSO shall establish alternate controls					
Interlocks on protective housing	Δ	Δ	Δ	Δ	Shall	Shall
Service access panels interlocked or require special tools for removal	Δ	Δ	Δ	Δ	Shall	Shall
Key control	>MPE	>MPE	>MPE	>MPE	Should	Shall
Viewing portals and display screens have means to reduce levels to <MPE	—	—	>MPE	>MPE	>MPE	>MPE
Collecting optics have means to reduce levels to <MPE	>MPE	>MPE	>MPE	>MPE	>MPE	>MPE
Totally open beam path	—	—	—	—	NHZ	NHZ
Limited open beam path	—	—	—	—	NHZ	NHZ
Enclosed beam path	*Not required if engineering or LSO-approved hazards analysis performed and administrative controls are in place*					
Remote interlock connector to allow for multiple shutdown devices such as "panic buttons"	—	—	—	—	Should	Shall
Attached beam stop or attenuator to reduce output <MPE if full output of laser isn't needed	—	—	—	—	Should	Shall
Activation warning systems such as lights or audible devices or a countdown	—	—	—	—	Should	Shall
Emission delay between annunciation of warning and laser firing	—	—	—	—	—	Shall
Indoor laser controlled area determination made by hazard analysis of LSO	—	—	—	—	NHZ	NHZ
Temporary laser controlled area during maintenance, etc. when protective housing and other engineering controls must be bypassed	Δ>MPE	Δ>MPE	Δ>MPE	Δ>MPE	—	—
Remote firing and monitoring	—	—	—	—	—	Should
Labels posted on laser equipment	Shall	Shall	Shall	Shall	Shall	Shall
Area posting of laser hazard warning signs/devices	—	—	—	Should	NHZ	NHZ
Administrative and Other Controls						
Standard/safe operating procedures	—	—	—	—	Should	Shall
Limiting output if laser is overpowered for job			—	Shall if LSO determined need		
Training operators and maintenance/service personnel	—	—	Should	Should	Shall	Shall
Operation/servicing by authorized personnel only	—	—	—	—	Shall	Shall
Standard/safe operating procedures governing alignment	—	—	Shall	Shall	Shall	Shall
Laser protective eyewear required if other measures are insufficient	—	—	—	—	Should if >MPE	MPE
Skin protection	—	—	—	—	MPE	MPE
Protective windows installed	—	—	—	—	NHZ	NHZ
Warning signs and labels of standard design	—	—	Should	Should	NHZ	NHZ
Fiber optic system controls	MPE	MPE	MPE	MPE	Shall	Shall
Public demonstration controls	MPE†	—	Shall	Shall	Shall	Shall

KEY:

Shall	Must be done
Δ	Shall if enclosed Class 3b or 4
MPE	Shall if MPE is exceeded
—	No requirement
Should	Should be done
NHZ	Analysis to define nominal hazard zone required
†	Applicable to UV and IR lasers

(From LIA/ANSIZ136.1-1993.)

based on the size of the angle subtended by that source in radian units. The AELs used to define laser classes are equal to the MPEs for the maximum allowable viewing time listed in the standard for visible and IR-A lasers, multiplied by the limiting aperture (typically the size of the pupil opening, which can range from 1 to 7 mm, as defined in the standard [see Table 11–P]). The MPEs for wavelengths above 1,400 nm are the only available guidance for nonlaser IR sources emitted at frequencies above 1,400 nm. Limiting aperture dimensions depend on wavelength and the expected duration of an exposure.

LIA/ANSI Z136.1-1993 uses different averaging times depending on the wavelength of the radiation involved. The averaging time for UV exposures is the duration of the expo-

Table 11–N. *Maximum Permissible Exposures for Laser Radiation for Intrabeam Viewing*

Wavelength (μm)	Exposure Duration	MPE (J/cm^2)	MPE (W/cm^2)	Notes
UV				
0.180–0.302	1 ns–30,000 s	3×10^{-3}	—	
0.303	"	4×10^{-3}	—	
0.304	"	6×10^{-3}	—	
0.305	"	10×10^{-3}	—	
0.306	"	16×10^{-3}	—	
0.307	"	25×10^{-3}	—	
0.308	"	40×10^{-3}	—	or $0.56t^{1/4}$, whichever is less
0.309	"	63×10^{-3}	—	See Table 11–Q for definitions
0.310	"	0.1	—	of limiting apertures.
0.311	"	0.16	—	
0.312	"	0.25	—	
0.313	"	0.40	—	
0.314	"	0.63	—	
0.315–0.400	1 ns–10 s	$0.56\ t^{1/4}$	—	
	10–30,000 s	1.0	—	
Visible and Near IR				
0.400–0.700	1 ns–18 μs	0.5×10^{-6}	—	
	18 μs–10 s	$1.8\ t^{3/4} \times 10^{-3}$	—	
0.400–0.550	10–10,000 s	10×10^{-3}	—	
0.550–0.700	$10–T_1$	$1.8\ t^{3/4} \times 10^{-3}$	—	
	T_1–10,000 s	$10\ C_B \times 10^{-3}$*	—	
0.400–0.700	10,000–30,000 s		$C_B \times 10^{-6}$*	See Table 11–Q for definitions
0.700–1.050	1 ns–18 μs	$0.5\ C_A \times 10^{-6}$*	—	of limiting apertures.
	18 μs–1,000 s	$1.8\ C_A\ t^{3/4} \times 10^{-3}$*	—	
	1,000–30,000 s		$320\ C_A \times 10^{-6}$*	
1.050–1.400	1 ns–50 μs	$5\ C_C \times 10^{-6}$*	—	
	50 μs–1,000 s	$9\ C_C\ t^{3/4}\ 10^{-3}$*	—	
	1,000–30,000 s		$1.6\ C_C \times 10^{-3}$*	
Far IR				
1.4–1.5	1ns–1 ms	0.1	—	
	1 ms–10 s	$0.56t^{1/4}$	—	
	10–30,000 s		0.1	
1.5–1.8	1 ns–10 s	1	—	
	10–30,000 s		0.1	Only exposure standard >1.4 μm
1.8–2.6	1 ns–1 ms	0.1	—	See Table 11–Q for definitions
	1 ms–10 s	$0.56\ t^{1/4}$	—	of limiting apertures.
	10–30,000 s		0.1	
2.6 mm–1 mm	1–100 ns	10 3 10^{-3}	—	
	100 ns–10 s	$0.56\ t^{1/4}$	—	
	10–30,000 s		0.1	

* See Table 11-P for definitions of C_A, C_B, C_C, C_E, and T_1.
(From LIA/ANSI Z136.1-1993.)

sure throughout a shift, similar to the averaging time for chemicals. The standard actually is based on accumulating a dose of UV energy rather than measuring or calculating the average exposure. The averaging time for visible exposures is 0.25 s, the operating time of aversion reflexes. The averaging time for IR exposures is 10 s.

This standard also gives protocols for evaluating repetitively pulsed exposures that are used when the pulse repetition rate exceeds one pulse per second. Pulses that occur less frequently than once per second are addressed by the standards shown in Table 11–Q. Computer applications are available to do routine laser safety calculations, but the user should know how to do the calculations on paper before beginning to routinely use the application and verify that the application works for the pulsing and wavelength scenarios of interest by comparing computer results to the results of paper calculations.

Pulsed laser exposure criteria are complicated and hard to apply. LIA/ANSI Z136.1-1993 specifies that the exposure interval for visible lasers is 0.25 s (it defines visible as ranging between 400 and 700 nm rather than 760 nm) whereas the exposure interval for IR lasers is 10 s. These exposure durations are applied concurrently in two procedures for determining MPEs and AELs for pulsed lasers, per paragraph 8.2.2 of the standard. People working with pulsed lasers need to understand this part of the standard completely, but a full discussion of paragraph 8.2.2 is beyond the scope of this chapter.

Table 11–O. *Maximum Permissible Exposures for Laser Radiation Skin Exposures*

Wavelength (μm)	Exposure Duration	MPE (J/cm²)	MPE (W/cm²)	Notes
UV				
0.180–0.302	1 ns–30,000 s	3×10^{-3}	—	or $0.56t^{1/4}$, whichever is less;
0.303	"	4×10^{-3}	—	3.5 mm limiting aperture
0.304	"	6×10^{-3}	—	
0.305	"	10×10^{-3}	—	
0.306	"	16×10^{-3}	—	
0.307	"	25×10^{-3}	—	
0.308	"	40×10^{-3}	—	
0.309	"	63×10^{-3}	—	
0.310	"	0.1	—	
0.311	"	0.16	—	
0.312	"	0.25	—	
0.313	"	0.40	—	
0.314	"	0.63	—	
0.315–0.400	1 ns–10 s	$0.56\ t^{1/4}$	—	
	10–1,000 s	1.0	—	
	1,000–30,000 s		1×10^{-3}	
Visible and Near IR				
0.4–1.4	1–100 ns	$2\ C_A\ 10^{-2}$*	—	
	100 ns–10 s	$1.1\ C_A t^{1/4}$*	—	3.5 mm limiting aperture
	10–30,000 s		$0.2\ C_A$ *	
Far IR				
1.4–1 mm	1–100 ns	10^{-2}	—	Only exposure standard >1.4 μm
	100 ns–10 s	$0.56t^{1/4}$	—	See Table 11–Q for definitions
	10–30,000 s		0.1	of limiting apertures.

* See Table 11-P for definition of C_A, C_B, C_C, C_E, and T_1.
(From LIA/ANSI Z136.1-1993.)

Controls

Engineering and administrative controls and personal protective equipment are used for lasers and optical radiation. The main engineering control for lasers is enclosure, often in the form of interlocked rooms and protective housings. Interlocked laser beam enclosures can range from plastic panels on a framework for research setups to sturdy metal boxes with person- or vehicle-sized access doors for IR laser cutting tools. Laser beams can be routed over or below walkways using mirrors and, possibly, elevated enclosures or tunnels. LIA/ANSI Z136.1-1993 calls for fail-safe interlocks, such as double interlocks connected in series, on access panels of enclosures of Class 3b or 4 laser beams. The interlocks either shut off the electrical power to the laser or drop a shutter into the beam at or within the housing of the laser itself. An important extension of interlocks is the remote interlock connection, which allows additional interlocks, including those located remotely, to trigger a shutdown of electric power to a laser or drop a shutter or filter into the beam. Remote interlocks can make up safety chains for laser systems covering large areas and include emergency panic button shutoffs.

Viewing portals, viewing screens, and optical instruments must be connected to interlocks or reduce beam intensity to acceptable levels for Class 4 lasers. LIA/ANSI Z136.1-1993 recognizes the use of fasteners requiring special tools as providing equivalent safety to interlocks for access panels. It is convenient to add room status lights (green for safe to enter, yellow for possibly unsafe to enter, and red for unsafe to enter) to the laser interlock system and to install a loudspeaker and buzzer near the room status lights so visitors can

Table 11–P. *Correction Factors for Intrabeam Viewing MPEs of Table 11–N and Table 11–O*

Correction Factor		Definition	Wavelength (μm)
C_A	=	1	0.400–0.700
C_A	=	$10^{2(\lambda-0.700)}$	0.700–1.050
C_A	=	5	1.050–1.400
C_B	=	1	0.400–0.550
C_B	=	$10^{15(\lambda-0.550)}$	0.550–0.700
C_C	=	1	1.050–1.150
C_C	=	$10^{18(\lambda-1.150)}$	1.150–1.200
C_C	=	8	1.200–1.400
C_E	=	1 (if the subtended angle, α, is α_{min})	0.4–1.4
C_E	=	α/α_{min} if the subtended angle is between α_{min} and 100 mradians	0.4–1.4
C_E	=	$\alpha/(100\ \alpha_{min})$ if the subtended angle is > 100 mradians	0.4-–1.4
T_1	=	$10 \circ 10^{20(\lambda-0.550)}$	0.550–0.700

α_{min} = 1.5 milliradians when $t \leq 0.7$s; $\alpha_{min} = 2\ t^{3/4}$ milliradians when 0.7 s < t < 10 s; α_{min} = 11 milliradians when $t \geq 10$ s.
(From LIA/ANSI Z136.1-1993.)

Table 11–Q. ***Limiting Apertures Used to Develop Accessible Emission Limits (AELs)***

		Eye Aperture		Skin Aperture	
Spectral Region (μm)	*Duration (s)*	*Diameter (mm)*	*Area (cm^2)***	*Diameter (mm)*	*Area (cm^2)***
≥0.180 to <0.400	10^{-9} to 0.25	1	0.0078	3.5	0.0962
	0.25 to 3×10^4	3.5	0.0962	3.5	0.0962
≥0.400 to <1.400	10^{-9} to 3×10^4	7	0.3848	3.5	0.0962
≥1.400 to <100	10^{-9} to 0.3	1	0.0078	3.5	0.0962
	0.3 to 10*	$1.5\ t^{3/8}$		3.5	0.0962
	10 to 3×10^4	3.5	0.0962	3.5	0.0962
≥100 to <1 mm	10^{-9} to 3×10^4	11.0	0.9503	11.0	0.9503

* This exposure duration normally would not be used for hazard evaluation.
** Area in cm^2 is used to calculate AELs.
(From LIA/ANSI Z136.1-1993.)

talk to the room occupants during laser operations. These boxes were developed and are used extensively at Lawrence Livermore National Laboratory, and are also commercially available.

A simple control, especially useful for lasers located in places where unauthorized people could find them, is a key-in-lock control, which makes it very unlikely that the laser could be inadvertently operated by unauthorized people. Of course, the operator must remove the key and take it when the laser is turned off.

Engineering controls are effective when a laser system is set up, but not while it is being set up or during maintenance. Thus, special caution, including heavy reliance on administrative controls and special warning signs, is needed during setup and maintenance. A recent review of laser accidents shows that 37.2 percent of laser accidents occurred during alignment. Techniques for reducing hazards during alignment include using low-powered alignment lasers. The alignment laser beam is brought into the path of the main laser beam and system adjustments are made using the less dangerous alignment beam; the accessible main laser beam power can also be reduced for setup or alignment, if practical. Alternatively, special laser alignment eyewear that blocks most of the light can be used during alignment after steps have been taken to ensure that the main beam cannot enter the eyes. ANSI Z136.1 specifies special warning signs to be used during setup. A variety of aids are available to make alignment easier even with protective eyewear:

- ➢ An IR disc that is mounted in an optical-component holder.
- ➢ IR or UV cards that glow with visible light when struck by an IR or UV laser beam.
- ➢ IR viewers that make the place where the beam strikes a surface show as a visible dot.
- ➢ Strong white paper or colored paper that fluoresces in different wavelengths (colors) when struck by a visible laser beam. The fluorescent radiation can pass through the lenses of laser safety eyewear intended for the laser wavelength. Some experimentation is needed to find which papers work.

Specular (mirror-like) reflections are more hazardous than diffuse reflections because virtually all of the beam's power is retained, as shown in Figure 11–23, and safety precautions always include eliminating all unnecessary specular reflectors. Most optical instrument manufacturers mount their products on shiny posts, but the posts are cylindrical, so a reflected beam will still be spread out. LIA/ANSI Z136.1-1993 includes formulae for calculating reflections from rounded mirrors. Painted walls and stipple-finished tools can easily be specular reflectors for CO_2 laser beams because the surface roughness that causes the diffuse reflections we see is smaller than 10.6 μm so the surface acts as if it is slick and causes specular reflections at 10.6 μm.

Administrative controls are used during setup and maintenance. Z136.1-1993 calls for calculating the nominal hazard zone (NHZ), where people could be exposed to laser beam levels above the MPEs, and excluding people from the NHZ by barriers, signs, flashing beacons, and the diligence of personnel authorized to be inside the NHZ. Warning signs should follow international conventions, applied in the United States through the ANSI Z535 series of standards; these specify colors, warning words, standard symbols, and

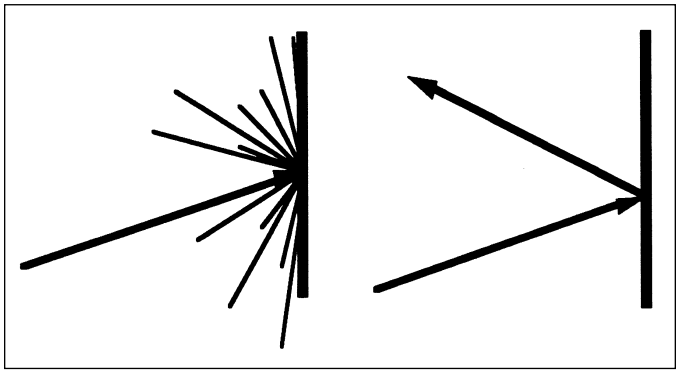


Figure 11–23. Diffuse reflections (left) dissipate the energy of incident radiation, so the reflection is not as bright as the incident radiation because it is scattered in many directions. Specular reflections (right) are much more dangerous because the beam bounces in only one direction, retaining most of its original intensity and hazard.

warning sign layout. The laser warning symbol is the familiar sunburst. The word *CAUTION* is used on signs and labels for Class 2 and 3a lasers and laser systems that do not exceed the appropriate MPE. The word *DANGER* must be used for other Class 3a lasers and all Class 3b and 4 lasers. Existing laser-safety signs and labels are grandfathered in by Z136.1-1993. The signs must specify essential precautions above the tail of the sunburst (shown in Figure 11–24) and describe the properties of the laser and the laser class below the center of the tail and the lower–right-hand corner of the sign, respectively.

Medical surveillance and training programs are required for users of Class 3b and 4 lasers. The laser safety program must include the following:

- ➢ A laser safety officer and, if the number and diversity of laser operations warrants, a laser safety committee
- ➢ Education of authorized personnel
- ➢ Application of the controls specified in the standard
- ➢ Accident reporting and investigation and action plans to prevent recurrence of incidents
- ➢ Medical surveillance as specified in the standard

Laser protective goggles must show the manufacturer, wavelengths they work against, and optical density, and must meet the provisions of the latest edition of ANSI Z87.1 for safety eyewear. As with all personal protective equipment, it is necessary to select laser eyewear of appropriate optical density for the type (wavelengths) of radiation encountered and the severity of exposure. Color coding is recommended for multilaser environments and eyewear manufacturers offer color-coded frames. Laser-protective eyewear usually includes glass or plastic lenses. In general, glass lenses are heavier, but offer more resistance to direct strikes by laser beams and often let through more light. As a rule, glass is often used when the average power of a laser exceeds about 100 mW.

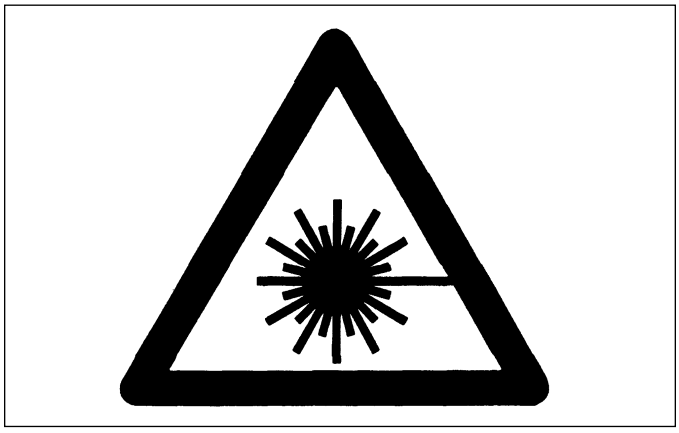


Figure 11–24. The internationally recognized sunburst laser warning icon. ANSI Z535 standards eliminate the tradition of using special colors for specific hazard warnings, but ANSI Z136.1-1993 makes limited use of a red symbol for *DANGER* signs. Symbols and narrative text now appear in black and colors are used to indicate degree of hazard (yellow and black for *CAUTION*, orange and black for *WARNING*, and red, black, and white for *DANGER*). The long tail symbolizes how laser beams retain their power over long distances. The same symbol, but without the tail, was proposed for intense nonlaser sources of optical radiation, but it is not widely used.

Laser Pointers

Laser pointers are now available at retail office supply stores. The first laser pointers were helium-neon (He-Ne) lasers emitting at 632 nm (red). But they were delicate because of the glass envelope of the He-Ne laser. Diode lasers rapidly replaced He-Ne lasers because they are more rugged and allow for compact, pen-sized pointers. Unfortunately, the early diodes emitted at 670 nm, where the visual response of the eye is much poorer than it is at 632 nm. This difficulty was overcome by raising the laser output from somewhere below one mW to a few mW. Although the visual response of the eye is exquisitely wavelength-sensitive, the vulnerability of the eye to thermal injury is not. The old He-Ne pointers were Class 2 lasers; the original diode pointers were Class 3a. The original He-Ne pointers bore a caution label; the diode laser pointers bear danger labels. Stories of cavalier use of laser pointers at lectures are common and these lasers are accessible to children. Fortunately, diode pointers emitting at 635 nm are now on the market and even shorter wavelength pointers can be expected as solid state laser technology advances. The new Class 2 laser diode pointers are both more brilliant and safer.

Safety officers should:

- ➢ Warn employees about the hazard of misusing diode laser pointers—they could cause injury if someone stares into the beam for a prolonged period.
- ➢ Replace Class 3a 670-nm pointers with Class 2 635-nm pointers.

Safety officers working for retailers should advise management to market only Class 2 laser pointers. The possibility that a child could misuse a Class 3a pointer cannot be overlooked.

Nonbeam Hazards of Lasers

The two greatest hazards of lasers, other than laser weapons, are electricity and fire. Electrocution from high-voltage power supplies and capacitor banks is a real hazard and can kill while most laser beam exposures cause some loss of vision at worst. A draft NFPA standard for laser fire protection advises that a continuous wave laser radiation creating an irradiance above beam irradiances <2 W/cm^2 is an ignition hazard. The beam could ignite flammable substances such as paper and solvents, so flammable materials must be kept out of Class 4 and some focused Class 3 laser areas. One partial exception is plastic walls of enclosures that glow where they are struck by visible or strong invisible laser beams while the area is occupied; fire-resistant plastics should be used for these applications. Objects that could be struck by laser beams must be selected to avoid toxic pyrolysis products; for

Table 11–R. *Summary of Laser Dye Handling Precautions Developed at Lawrence Livermore National Laboratory*

Action	Dye hazard class L	M	S
Work Practices			
Avoid eating, drinking, smoking, or storing food, drinks, materials, or cosmetics in dye work areas	X	X	X
Post signs to this effect	—	—	X
Keep dye areas clean; clean up after work	X	X	X
Cap off dye lines not in use	X	X	X
Minimize quantities of dyes and solutions >1% in use or storage	—	—	X
Limit access to dye and work areas with signs	—	—	X
Avoid having janitors do dye cleanup	—	X	X
Store dyes and solutions >1% in double, labeled containers	—	—	X
Use toxic-dust vacuum to clean up dye spills	—	—	X
Personal Protective Equipment			
Use safety eyewear	X	X	X
Use lab coat	—	X	X
Use nitrile or neoprene gloves to handle solutions, impervious gloves to handle powders	X	X	X
Fire Safety			
Keep heat, flames, ignition sources away	X	X	X
Keep solvents and dye solutions in colored, labeled containers	X	X	X
Keep alcohol wastes in labeled safety cans	X	X	X
Avoid oxidizers	X	X	X
Equipment			
Pressure test systems	X	X	X
Install drip pans under systems, enclose systems if possible	X	X	X
Provide safety shower/eyewash	—	X	X
Mix dyes in hood or glove box	—	X	X
Mix dyes in glove box	—	—	X
Avoid cracks, crevices, matte-textured surfaces, and dark colors	—	—	X
Avoid false floors, if possible	—	—	X
Provide a designated dye-storage area	—	—	X
Provide separate storage for dye-soiled equipment	—	—	X
Use mechanical pipetting aids	—	—	X
Spills			
Clean up spills	X	X	X
Call for help if more than 100 mL of solution is spilled, or if exposure to dye powder is possible	X	X	X
Notify safety and health department of all spills	—	—	X

X = listed precaution.
— = not a listed precaution.
L = limited precaution class (good chemical lab practice, assigned to dyes known to be neither highly toxic nor mutagenic/carcinogenic).
M = moderate precaution (dyes known to be highly toxic or to have unknown toxic, mutagenic, or carcinogenic properties).
S = strict precaution (mutagenic materials, treated with same precautions as carcinogens).

example, some polyurethanes and epoxies produce hydrogen cyanide when they burn. Dye lasers are particular fire hazards because most use solutions of dye in an alcohol, dimethyl sulfoxide (DMSO), or some other flammable or combustible solvent. The dye solution may be located close to pumping energy sources such as flash lamps, which can add the energy needed to ignite the solvent.

Some lasers use flash lamps to supply pumping energy. Flash lamps can explode if dropped, struck, or improperly handled, posing a laceration hazard.

Laser beams can pyrolyze organic materials, and investigators who have looked at the pyrolysis products report finding polycyclic aromatic hydrocarbons (PAHs), the carcinogenic substances found in chimney soot. Thus, pyrolysis products must be controlled both in the air and as deposits on surfaces. For example, Kwan (1990) found that epoxy-reinforced graphite composite materials emit a variety of PAHs when cut by CO_2 lasers. It is also now known that viable organisms can be found in the plumes created when lasers are used to cut tissue.

Many laser dyes were brought to the market with essentially no toxicology screening and often come from chemical families that include mutagens or highly toxic materials. Mosovsky and Miller, 1986, working with Avila, Felton, and Lewis, found that a number of laser dyes are mutagenic; the chemistries of these dyes are such that a positive mutagenicity finding is cause for concern that the material may be a carcinogen. The original dye recipes used DMSO solvent, which carries other materials through the skin. However, most butyl and some neoprene and nitrile gloves are effective for blocking DMSO. DMSO can increase absorption through the skin of the dye, which may be toxic or mutagenic; it also contains sulfur, which makes disposal by incineration difficult. Dioxane, a potential carcinogen that also forms explosive peroxides if left in contact with air for prolonged time periods, should be avoided as a solvent. Chlorinated solvents are costlier to dispose of than glycols or alcohols because it is difficult to send chlorinated solvents to incinerators. Precautions for laser dyes developed at Lawrence Livermore National Laboratory are summarized in Tables 11–R and 11–S. A variation on this theme is found in the recipe for Q-switching dyes. Dye-filled cells can be used for Q-switching. Some Q-switching dyes use ethylene dichloride, a potential carcinogen, as the solvent.

Excimer lasers use halogen mixtures such as 5 percent or less of fluorine or hydrogen chloride in inert gas. These mixtures are toxic, but fortunately the corrosiveness of the halogens is moderated by dilution in inert gases. Care is still needed in selecting corrosion-resistant materials, and consideration must be given to venting these gases during cavity refilling and emergencies. Passivation procedures, which use small quantities of the reactive gas to lay down a nonreactive deposit on surfaces that will later be exposed to larger flows of that gas, must be used to prepare piping for halogen gas service and avoid serious piping failures. Gas-handling equipment that is corrosion-resistant, highly automated, and designed to maximize safety and convenience is now very common in the semiconductor industry. Excimer laser users

can obtain information about this technology from gas suppliers affiliated with gas-handling equipment manufacturers.

Other forms of radiation, such as flash lamp radiation, electromagnetic fields from power supplies, and x rays from high-voltage devices, can also be hazardous. It may be necessary to provide additional shielding or implement additional controls for these fields and other forms of radiation. Radiation from flash lamps, which can contain 100–1,000 times the energy of the laser beam, could be a hazard during setup and maintenance.

Hazardous materials can be found in optical components (such as heavy metals in detectors), components of lasers (such as beryllia heat sinks of electronic parts), or miscellaneous applications (such as coolants). Thus, an industrial hygiene review of laser maintenance procedures is warranted.

Other Regulatory Concerns with Lasers

OSHA has promulgated construction safety standard 29 *CFR* 1926.54 for the use of lasers in tasks such as alignment, although general industry uses of lasers are covered by ANSI Z136.1-1993 through the *UAW, Brock v. General Dynamics Land Systems Division* decision because OSHA general industry standards do not address lasers. The use of laser protective eyewear is covered by the eye and face protection standard, 29 *CFR* 1910.132. The OSHA construction standard specifies that those who could be exposed to direct or reflected light above 5 mW must be provided with laser eye protection and that only mechanical or electronic devices may be used to guide the alignment of a laser. The standard also sets exposure criteria summarized below:

Direct staring limit	1 $\mu W/cm^2$
Incidental observing limit	1 mW/cm^2
Diffused reflected light	2.5 W/cm^2

The LIA/ANSI Z136 committee has also issued standards Z136.2 and Z136.3 for use of lasers in fiber-optic communications systems and medical applications, respectively. The Z136.3 standard addresses the same concerns as the Z136.1 standard, but allows for greater flexibility and use of administrative controls.

The Center for Devices and Radiological Health (CDRH) of the Food and Drug Administration sets standards for commercial laser products that specify the types of safety devices that must be installed for commercial equipment using lasers. The CDRH also uses control classes based on AELs that are defined in their standard for laser devices (21 *CFR*, part 1040). CDRH specifies using interlocks, beam stops/shutters, and key-in-lock controls. CDRH also has very explicit requirements for audible and visible alarms to announce when a laser is functioning and, for Class 4, when a laser is about to function. The CDRH regulations also include an incident reporting procedure.

MEASURING OPTICAL RADIATION

Two types of detectors are widely used: thermal and quantum. Thermal detectors are fundamentally no different from globe thermometers used in heat stress studies. They consist of a sensor embedded in an object that is dark-colored to absorb IR radiation, warm up, and produce a measurable response in the detector. Relatively small, lightweight objects are desirable for thermal sensors because they change temperature rapidly, leading to faster response times (but still not fast enough to measure pulsed lasers). A variant of the thermal detector is the pyroelectric detector, which measures the rate of temperature change in crystals. This is much faster than a conventional thermal detector and, with some caution, these can be used for repetitively pulsed lasers. Thermal detectors are best for IR measurements. The heat-absorbing coatings vary in how well they absorb IR, so one should obtain information about the absorption properties of the coating before buying a thermal sensor. Another note of caution is that these detectors respond to temperature changes, so changing the room thermostat can produce a response in the instrument.

Quantum detectors emit electrons in response to being struck by radiation and are best suited for use in the UV, visible, and IR-A bands (up to 1,100 nm). These can be very fast. The detectors are often made of alloys such as cesium telluride, lead telluride, or lead selenide and the responses of the detectors to radiation of differing wavelengths are different. A buyer should check with the instrument vendor about the suitability of a detector for the radiation of interest. Note that no procedure exists for field verification of the ODs of laser eyewear.

LIGHTING

Insufficient light causes accidents and reduces work performance. One needs adequate lighting to see hazards in the workplace and to read information such as text and dials. Most lighting concerns are quantitative, but some qualitative concerns may also arise such as contrast, reflections, and color.

The Illumination Engineering Society (IES) advises that 20 footcandles of illuminance are needed for tasks requiring sustained seeing. This is also one aspect of nonionizing radiation covered by various OSHA regulations, as summarized in Table 11–T. IES/ANSI RP-7-1991 specifies the following illuminance levels for safety in normal conditions (where light will not ruin a process or pose a safety hazard):

	Illuminance Level (footcandles)	
Degree of Hazard	*Low Activity Level*	*High Activity Level*
Slight Hazard	0.5	2
High Hazard (obstacle in path)	1	5

Illuminance is similar to irradiance and power density, but the levels of light of various wavelengths are weighted in terms of their impact on the functioning of the cone cells of the retina, which are involved in color and detailed vision. The units of illuminance are the lux and the footcandle; 1 lux = 10 footcandles. The dominant quantitative standards for indus-

Table 11–S. ***Laser Dye and Solvent Control Classes in Use at Lawrence Livermore National Laboratory***

Materials/Synonyms	*Control Class*	*Comments*
BBQ	M	Nonmutagenic, unknown toxicity
Benzyl alcohol	L	Moderate toxicity, low vapor pressure
Carbazine 720	M	Nonmutagenic, unknown toxicity
Coumarin 1/460	M	Nonmutagenic, moderately toxic
Coumarin 2/45	M	Nonmutagenic, unknown toxicity
Coumarin 30/515	S	Mutagenic, unknown toxicity
Coumarin 102/480	S	Strong mutagen, unknown toxicity
Coumarin 120/440	M	Nonmutagenic, unknown toxicity
Coumarin 314/504	M	Nonmutagenic, unknown toxicity
Coumarin 420	M	Nonmutagenic, unknown toxicity
Coumarin 481	M	Nonmutagenic, unknown toxicity
Coumarin 498	M	Unknown mutagenicity, unknown toxicity
Coumarin 500	S	Mutagenic, unknown toxicity
Coumarin 535	S	Mutagenic, unknown toxicity
Coumarin 540A	M	Nonmutagenic, unknown toxicity
Cresyl violet 670	S	Very strong mutagen, unknown toxicity
1,3,5,7-Cyclooctatetrene (COT)	M	Unknown mutagenicity, unknown toxicity
DCM	S	Very strong mutagen, unknown toxicity
p,p'-diaminoquaterphenyl	M	Nonmutagenic, unknown toxicity
p,p'-diaminoterphenyl	S	Mutagenic, unknown toxicity
Dioxane	M	Moderate toxicity
DMSO	M	Moderate toxicity
DODCI	M	Unknown mutagenicity, unknown toxicity
DQOCI	M	Unknown mutagenicity, unknown toxicity
DPS	M	Doubtful bacterial mutagen, unknown toxicity
Ethylene dichloride (1,2 dichloroethane)	M	Suspected carcinogen; avoid inhalation of vapors
Ethyl alcohol	L	Low toxicity
Ethylene glycol	M	Moderate toxicity, low vapor pressure
Fluorescein 548	M	Unknown mutagenicity, unknown toxicity
IR-26	M	Unknown mutagenicity, unknown toxicity
IR-125	M	Unknown mutagenicity, unknown toxicity
IR-132	M	Unknown mutagenicity, unknown toxicity
IR-140	M	Unknown mutagenicity, unknown toxicity
IR-144	M	Unknown mutagenicity, unknown toxicity
Kiton Red 620	L	Nonmutagenic, practically nontoxic
Kodak Q-Switch #2	M	Unknown mutagenicity, unknown toxicity
Kodak Q-Switch #5	M	Unknown mutagenicity, unknown toxicity
LD-390	M	Unknown mutagenicity, unknown toxicity
LD-490	S	Mutagenic, unknown toxicity
LD-688	S	Mutagenic, unknown toxicity
LD-700	M	Nonmutagenic, unknown toxicity
LDS-698	S	Mutagenic, unknown toxicity
LDS-722	S	Strong mutagen, unknown toxicity
LDS-750	M	Unknown mutagenicity, unknown toxicity
LDS-751	M	Unknown mutagenicity, unknown toxicity
LDS-820	M	Unknown mutagenicity, unknown toxicity
LDS-867	M	Unknown mutagenicity, unknown toxicity
9-Methylanthracene	S	Mutagenic, unknown toxicity

Continues

Table 11–S. ***Laser Dye and Solvent Control Classes in Use at Lawrence Livermore National Laboratory (Continued)***

Materials/Synonyms	*Control Class*	*Comments*
Methyl alcohol	L	Moderate toxicity
Bis-MSB	M	Nonmutagenic, unknown toxicity
Nile Blue 690	S	Commercial grade is strongly mutagenic; purified dye is not. Unknown toxicity.
Oxazine 720	M	Nonmutagenic, unknown toxicity
Rhodamine 6G/590	M	Moderately toxic. National Toxicology Program tests did not demonstrate strong carcinogenicity. Commercial-grade dye has been found to induce injection-site tumors.
Rhodamine 110/560	S	Weak mutagen, unknown toxicity
Rhodamine 610/B	M	Nonmutagenic, moderately toxic
Rhodamine 640	M	Nonmutagenic, unknown toxicity
Sulforhodamine	M	Unknown mutagenicity, unknown toxicity
Stilbene 420/3	L	Nonmutagenic, practically nontoxic
N,N,N',N'-tetraethyldiaminoquaterphenyl	M	Nonmutagenic, unknown toxicity
N,N,N',N'-tetraethyldiaminoterphenyl	S	Strong mutagen, unknown toxicity

L = limited control class; M = moderate control class; S = strict control class. Precautions to be followed for the L class are given in Table 11–R. Dye/solvent mixtures with less than 1 percent dye must be handled as appropriate to the solvent, with the exception that strict-class requirements for container and equipment labeling and spill cleanup must be followed when strict-class dyes are used. When using dye/solvent mixtures with more than 1 percent dye, follow the precautions for the component in the strictest control class.

The appropriate mutagen potency of the dye in the standard Ames *Salmonella* assay is as follows: weak mutagen = <100 revertants/mg; mutagenic = 100–1,000 revertants/mg; strong mutagen = 1,000–10,000 revertants/mg; very strong mutagen = ≥10,000 mutagens/mg. The Ames test is a reliable predictor of whether a compound is a carcinogen in mammals, but it does not predict the potency of the carcinogen. Thus, a weak Ames mutagen could be a strong carcinogen. Ames test data are used because animal testing is more costly and has not been done on most dyes.

trial lighting in the United States are IES/ANSI RP-1-1982 and RP-7-1991, which address office and industrial lighting, respectively. These standards replace the historical telephone-directory-style list of tasks and listed lighting levels with a procedure in which workplaces, work force, and tasks are analyzed for type of task, age, reflectance of room surfaces, and (in some cases) whether the seeing task is unimportant, important, or critical. Important aspects of any seeing task are object size (the bigger it is, the easier it is to see), contrast, time available to do the seeing job, and luminance. RP-7 notes that luminance is often the only factor that can be controlled. Illuminances are specified in ranges for nine categories (A through I); ranges of three levels of illuminance are specified for each category. The analyst reviews the other factors to determine whether to select from the low, middle, or high end of the illuminance range for each category. The categories and specified illuminances are listed in Table 11–U; the work force and environmental/task factors are summarized in Table 11–V.

Common qualitative concerns include glare (particularly off of VDT screens), contrast, and color. Glare, either reflected or direct, is still a major concern. Reflected glare is usually a specular reflection of a sunlit window or lamp off of a screen or other shiny surface that partially obscures or veils the scene at the reflection. Direct glare is a relatively bright object, such as an unshaded window, in an otherwise dark area that prevents the eyes from adapting to the dark area. Reflected glare can be controlled by locating the screen or other surface of interest so it does not reflect the images of windows or lamps.

A screen can be angled so it does not reflect the images of lamps or windows into the user's eyes. In some cases, visors or partitions can be used to block light from lamps or windows. Another option is to place a textured surface above the object that breaks up specular reflections while allowing the light from the object below it to pass through. Dimpled plastic is often used.

RP-7 devotes an entire Annex to the subject of glare. RP-7 also gives guidance for lighting contrast, listed in Table 11–W. A gradation of contrasts is sought between the task and its immediate and more remote visual surroundings. In essence, strong lighting can exist in an area of moderate lighting, which can be surrounded by a dimly lit or unlit expanse, but darkness should not immediately surround brightness. An example of harsh contrast is a lit desk in a poorly lit warehouse. The lamp at the desk should be supplemented by area lighting to avoid contrast problems. People look away from their visual tasks from time to time, so the person at this desk would probably not wish to stay there because the visual contrast between the desk and its visual surroundings is too great for comfort.

Nonlaser lighting adheres to the inverse square law. This means that lights must be placed close to areas being lit if the lighting is needed to perform a task. Sometimes, this cannot be done by area lighting alone. A warehouse may need area lights placed above the heights of shelves and forklift trucks, so supplemental lighting, provided by floor or desk lamps, may be needed at desks located in the warehouse. The limits of supplemental lighting include harsh contrast, already

Table 11–T. *Summary of OSHA Regulations Concerning General Lighting*

Regulation	*Summary*	
1910.179(c)(4): Cranes	Cab lighting shall be adequate.	
1910.303(g)(1)(v): Electrical work areas	Illumination shall be provided.	
1910.303(h)(3)(ii): Lighting maintenance	Adequate illumination shall be provided.	
1910.333(c)(4): Electrical work practices	Spaces containing energized parts shall be illuminated; work shall not be performed in and people shall not reach into unlit spaces.	
1910.38(q): Exits	Exit signs shall be lit by a reliable light source >5 footcandles.	
1910.120: Hazardous waste site operations	Quantitative specifications: Area	Illumination (footcandles)
	General work areas	5
	Excavation and waste areas, loading platforms, refueling, and field maintenance areas.	3
	Indoors: warehouses, corridors, hallways, and exit ways.	5
	Tunnels, shafts, and general underground work areas. (Exception: ≥10 footcandles is required at tunnel and shaft heading during drilling, mucking, and scaling. MSHA-approved cap lights acceptable for use in the tunnel heading).	5
	General shops (mechanical and electrical equipment rooms, active storerooms, barracks or living quarters, locker or dressing rooms, dining areas, indoor toilets, and workrooms).	10
	First-aid stations, infirmaries, and offices.	30
1910.142(g): Labor camps	Each habitable room shall have at least one ceiling light fixture and a floor or wall outlet. Laundry rooms, toilets, and rooms where people congregate shall contain a ceiling or wall fixture. Toilets and storage rooms shall be lit at ≥20 footcandles 30 in. above the floor. Other rooms, including kitchens and living quarters, shall be lit ≥30 footcandles 30 in. above the floor.	
1910.219(c)(5)(iii): Power transmission equipment in basements	Lighting shall conform to ANSI A11.1-1970.	
1910.68(b)(6)(iii): Manlifts	Lighting ≥5 footcandles shall be provided at each landing when lift is operating.	
1910.68(b)(14): Manlifts	Lighting ≥1 footcandles shall be provided in runs when lift is operating.	
1910.178(h): Industrial trucks	Supplemental lighting shall be provided where lighting is ≤2 lumens/ft^2.	
1910.261(b)(7): Pulp and paper mills	Emergency lighting shall be provided where operators must stay during emergencies, in passageways, stairways, and aisles used for emergency exit, and at first-aid and medical facilities.	
1910.261(c)(10): Pulp and paper mills	Loading/unloading areas shall be lit in accordance with ANSI A11.1-1970.	
1910.266(e)(15): Pulpwood logging	Lighting shall be provided for night work if needed.	
1910.265(c)(5)(iii): Sawmills	Stairway shall be adequately illuminated.	
1910.265(c)(9): Sawmills	Work areas shall be provided with adequate illumination.	
1910.265(c)(23)(iii): Sawmills	Fuel houses and bins shall have adequate exits and lighting.	
1910.268: Telecommunications	Adequate lighting shall be provided.	
1926.56: Construction	Areas not covered by the following table shall be illuminated in accordance with ANSI A11.1-1970.	
	Quantitative specifications: Area	Illumination (footcandles)
	General construction area lighting	5
	General construction areas, concrete placement, excavation and waste areas, access ways, active storage areas, loading platforms, refueling, and field maintenance areas.	3
	Indoors: warehouses, corridors, hallways, and exit ways.	5
	Tunnels, shafts, and general underground work areas. (Exception: ≥10 footcandles is required at tunnel and shaft heading during drilling, mucking, and scaling. MSHA-approved cap lights acceptable for use in the tunnel heading).	5
	General construction plant and shops (batch plants, screening plants, mechanical and electrical equipment rooms, carpenter shops, rigging lofts and active storerooms, barracks or living quarters, locker or dressing rooms, dining areas, and indoor toilets and workrooms).	10
	First-aid stations, infirmaries, and offices.	30

Table 11–U. ***Illuminance Categories of IES/ANSI RP-7-1991***

Type of Activity	*Examples*	*Illuminance Category*	*Range of Illuminance (footcandles)*	*Reference Workplane*
Public spaces with dark surroundings	Aircraft ramp area	A	2–3–5	
Simple orientation for short visits	Active storage area of a farm, VDT screens	B	5–7.5–10	General lighting throughout spaces
Working spaces where visual tasks are only occasionally performed	Active traffic area of a garage, elevators/escalators	C	10–15–20	
Performance of visual tasks of high contrast or large size	Simple assembly or inspection	D	20–30–50	
Performance of visual tasks of medium contrast or small size	Hand decorating in a bakery, mail sorting	E	50–75–100	Illuminance on task
Performance of visual tasks of low contrast or very small size	Finished lumber grading, model making	F	100–150–200	
Performance of visual tasks of low contrast and very small size over a prolonged period	Sewing clothes	G	200–300–500	Illuminance on task obtained by a combination of general and local (supplementary) lighting
Performance of very prolonged and exacting visual tasks	Exacting inspection	H	500–750–1,000	
Performance of very special visual tasks of extremely low contrast and small size	Cloth inspection and examining (perching) of sewn products	I	1,000–1,500–2,000	

mentioned, and also the possibility that the supplemental lighting could cause direct glare for people in the surrounding area. Energy conservation and safety needs can be reconciled by using motion detectors to activate area lighting when a person enters an area. Building and lighting cleaning and painting can make a tremendous difference in lighting by causing more of the light emitted from lamps to be reflected to places where people are working. Light, matte-textured surfaces are preferred. Matte textures avoid specular reflections and reflected glare. RP-1 and RP-7 give guidance about how reflective surfaces should be.

Color can be a problem if unusual fluorescent tubes or colored incandescent bulbs are installed. White light contains radiation associated with every color we can see; colored lights radiate selected wavelengths more intensely. Colored lighting is useful for some jobs, such as blue-enhanced fluorescent tubes for greenhouse lighting or yellow-orange low-pressure sodium lamps for abundant yet cheap safety lighting at night. Colored lighting without some benefit can create difficulties. Colors may be harder to perceive when nonwhite lighting is used. Yellow and white objects could, for example, both appear the same in yellow or red lighting, so yellow signs and warning devices could become unreliable and blue surfaces would appear to be black.

Concern has been expressed about the safety of fluorescent tubes. Fluorescent tubes contain a minute amount of mercury that conducts electric current and glows in the ultraviolet portion of the spectrum. The UV is absorbed by phosphors that line the tubes and is reradiated as visible

Table 11–V. ***Factors Influencing Assigning Illumination Levels Within Illuminance Categories of IES/ANSI RP-1-1982 and RP-7-1991***

For Illuminance Categories A Through C in Industrial and Office Settings

	Weighting		
Room and Occupant Characteristics	*Low End of Range*	*Mid-Range*	*High End of Range*
Occupant ages	<40	40–55	>55
Room surface reflectances	>70%	30–70%	<30%

For Illuminance Categories D Through I in Industrial and Office Settings

	Weighting		
Task and Worker Characteristics	*Low End of Range*	*Mid-Range*	*High End of Range*
Occupant ages	<40	40–55	>55
Speed or accuracy of seeing	Not important	Important	Critical
Reflectance of task background	>70%	30–70%	<30%

Table 11–W. ***IES/ANSI RP-7-1991 Recommended Maximum Luminance Ratios***

	Environmental Group		
Situation	*A*	*B*	*C*
Between tasks and adjacent darker surroundings	3 to 1	3 to 1	5 to 1
Between tasks and adjacent lighter surroundings	1 to 3	1 to 3	1 to 5
Between tasks and adjacent more remote darker surfaces	10 to 1	20 to 1	Control not practical
Between tasks and adjacent more remote darker surfaces	1 to 10	1 to 20	Control not practical
Between luminaires (or windows, skylights, etc.) and surfaces adjacent to them	20 to 1	Control not practical	Control not practical
Anywhere within normal field of view	40 to 1	Control not practical	Control not practical

Environmental groups: A—interior areas where reflectances of entire space can be controlled in line with recommendations for optimum seeing conditions; B—areas where reflectances of immediate work area can be controlled, but control of remote surroundings is limited; C—areas (indoor or outdoor) where it is impractical to control reflectances and difficult to alter environmental conditions.

light. ICNIRP issued a position statement that advises that UV emissions from fluorescent tubes are not a problem. Mercury vapor lamps are also used for lighting and they generate UV that is absorbed by an outer glass sheath. Mercury vapor lamps are safe unless the outer sheath is broken. A mercury vapor lamp with a broken sheath should be turned off and replaced immediately. It should be noted that disposing of fluorescent tubes is associated with other industrial hygiene concerns. Tube-breaking equipment can be noisy and heavily contaminated with toxic mercury metal, which can accumulate in tube breaking equipment. Fluorescent tubes contained highly toxic beryllium salts in the 1940s. Cadmium compounds were used, but their use was discontinued in the late 1980s, so cadmium exposure remains a potential hazard for tube breakers.

Lighting measurements are usually made 30 in. above the floor to measure the illumination striking surfaces that are to be seen. Special measurements can be made on surfaces of interest, such as desktops and working surfaces. The instruments used are typically inexpensive photoelectric devices. It is noted that IES developed guidance for lighting VDT workplaces, RP-24-1989, which is listed in the Bibliography.

SUMMARY

- ➢ Nonionizing "radiation" is often not radiation, but rather discrete electric and magnetic fields that exist independently of one another, whereas the fields in radiation are rigidly interrelated. The frequency below which it is assumed one is dealing with fields rather than radiation is 300 MHz.
- ➢ Electric fields are caused by nonmoving or moving electric charges and the electric field increases as the quantity of charge increases. Magnetic fields are caused by the flow of electric charges, or electric current, and increase as more current flows. In other words, electric charges create electric fields and moving them creates magnetic fields.
- ➢ The frequency of electromagnetic radiation times its wavelength equals its speed of travel, very close to 300,000,000 m/s in air or a vacuum. The frequency of electromagnetic radiation is the number of times the fields go through a complete cycle of polarity and strength change. Frequencies are expressed in hertz (Hz), the number of polarity and strength changes that occur in a second. The wavelength is the distance traveled as the radiation goes through that cycle of polarity and strength change. Higher frequencies mean shorter wavelengths and lower frequencies mean longer wavelengths.
- ➢ The various frequencies of the electric and magnetic field are divided into the electromagnetic spectrum. This is divided into subradiofrequency fields, which have frequencies below 3,000 Hz, radiofrequencies from 3,000 to 300,000,000,000 Hz including microwaves, which span 300,000,000 to 300,000,000,000 Hz, and optical radiation with higher frequencies and energies.
- ➢ Electromagnetic devices can be thought of as containing a source of energy, a transmission path, and a receiver of the energy.
- ➢ The exposure guideline for static magnetic fields was set by ICNIRP at 200 mT (2,000 [G]). The exposure guideline for static electric fields was set by ACGIH at 25 kV/m.
- ➢ ACGIH and ICNIRP issued ELF exposure criteria for workers based on avoiding induced currents that are stronger than those already created in the body by the normal functioning of nerves and muscles.
- ➢ Radiofrequency exposure standards are based on avoiding hazardous electric current flows at frequencies below a few MHz and on avoiding excessive rates of energy deposition at higher frequencies. Energy deposition is most significant at frequencies where a person's height is 20–40 percent of the wavelength of the radiation in air (30–300 MHz). At frequencies above a few GHz, energy deposition occurs mainly in the skin. The frequency of 300 GHz has a wavelength of 1 mm and higher frequencies are classified as IR radiation.
- ➢ Optical radiation is described by its wavelength and is divided into IR (760 nm–1 mm), visible (400–700 nm), and UV (variously 4 or 100 nm–400 nm). There are TLVs® for all nonlaser optical radiation from 180–1,400 nm and LIA/ANSI Z136.1-1993 addresses wavelengths from 180 nm to 1 mm. Shorter wavelengths are absorbed by oxygen to make ozone.
- ➢ Laser radiation is monochromatic (literally one color) or has just a few wavelengths, coherent (well-organized), and bright. Coherent radiation is very directional, so lasers can project intense or hazardous energies over longer distances than nonlaser sources of optical radiation.

- ➢ Laser radiation with wavelengths between 400 and 1,400 nm, the ocular hazard region, can be intensely focused on the retina. This makes lasers operating in this wavelength range particularly hazardous.
- ➢ Lasers are controlled by dividing them into hazard classes ranging from 1 (essentially harmless) to 4 (very hazardous). Precautions become more stringent as the hazard class increases.
- ➢ OSHA has limited standards for nonionizing radiation, but can enforce consensus standards according to the *UAW, Brock v. General Dynamics Land Systems Division* decision. These standards come from the ACGIH, the ICNIRP, the IEEE, and the LIA and are referenced in the Bibliography. European international organizations, particularly Swedish and Finnish organizations, are also active in this area.
- ➢ Industrial lighting standards relate to safety and productivity. They are promulgated by the IES.

Nonionizing radiation is becoming more and more a part of our lives on and off the job. Dealing with it will be one of the larger challenges facing the industrial hygiene profession in the future.

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Chapter 12

Thermal Stress

by Thomas E. Bernard, PhD, CIH

Thermal stress is a significant physical agent in many working environments. Just considering routine work out-of-doors, air temperatures between –20 to 110 F are expected over different regions of the United States. Other countries may reasonably expect temperatures beyond that range. Human-made environments from freezers to ovens extend the range of thermal environments in which work is expected. Because tasks must be performed under adverse thermal conditions, this chapter provides guidance for recognition, evaluation and control of work in thermal extremes.

DEGREES OF THERMAL STRESS

Conceptually, work can occur in one of five zones along the continuum of thermal stress. In the middle is the comfort zone. Here, most people would report thermal sensations as being acceptable (neither hot nor cold). In the comfort zone, the demands for physiological adaptation are modest and productivity should be the greatest. The comfort zone is described at the end of this chapter to provide information to health and safety professionals who may be asked to evaluate the thermal conditions with comfort as a goal.

On either side of the comfort zone are the discomfort zones for heat and cold stress. Under these conditions, most people should be able to safely work without experiencing a disorder related to the stress (i.e., heat-related or cold-related disorders). They will report sensations of cold or heat, productivity and quality of work may decrease, and the risk of accidents may increase. The goal of most evaluation schemes for occupational heat and cold stress is to limit exposures to the discomfort zone.

The health risk zone for heat and cold stress are the outer zones of the thermal stress continuum. The physiological adaptations have reached their limits and work capacity is severely limited. In the health risk zone, the likelihood of

heat and cold stress-related disorders increases markedly. Health and safety professionals should manage exposures in the health risk zone. Management of exposures in the health risk zone is the principal theme of this chapter.

Of course, there are no firm boundaries to these zones because the boundaries depend on the environment, individuals, and season as well as many unknown variables. But we should try to control the thermal stress factors for the less tolerant workers in order to minimize the risk of injuries and illness to the lowest reasonable level. The major emphasis on evaluation and control is placed on the transition from the discomfort zone to the health risk zone for both heat and cold stress.

THERMAL BALANCE

Model of Thermal Balance

Three factors influence the degree of thermal stress. The most obvious factor is the climatic conditions of the environment. The other two factors are work demands and clothing. The tradition for more than 40 years is to describe thermal balance by an equation with major avenues of heat exchange between the body and the environment represented by a term in the equation. (There is no uniformly accepted version but the reader will not have problems reconciling different versions as they are found.)

$$S = (M + W) + R + C + K + (C_{resp} + E_{resp}) + E \qquad (1)$$

where S = heat storage rate
M = metabolic rate
W = external work rate
R = radiant heat exchange rate
C = convective heat exchange rate
K = conductive heat exchange rate
C_{resp} = rate of convective heat exchange by respiration
E_{resp} = rate of evaporative heat loss by respiration
E = rate of evaporative heat loss

Most versions of the heat balance equation use ± instead of +, especially in front of R and C. The purpose is to emphasize that the heat exchange represented by R, C, K, and C_{resp} can be in either direction. A more rigorous sign convention is used in this chapter. A positive value for any of these terms (as opposed to the sign in front of the term) means that the heat is gained by the body and a negative value means that heat is lost from the body. The values for M and $(M + W)$ can only be positive. The values for W, E_{resp} and E are always negative, meaning that there is only heat loss associated with these terms. Each term has the unit of energy per unit of time; that is, the terms represent rates of energy transfer. The international units (SI units) are watts, and other units that are reported include kcal/h, kcal/min and Btu/h. Sometimes the rates are reported as normalized values to body surface area.

S—HEAT STORAGE RATE

If the value for S is zero, the body is in thermal equilibrium, and heat gain is balanced by loss from the body. If S is positive, the body is gaining heat at the rate indicated by the value of S. If the value of S is negative, the body is losing heat, and body temperature is decreasing.

M—METABOLIC RATE

Chemical reactions occur continuously inside the body. These serve to sustain life (basal metabolism) and meet the demands of work (muscle metabolism). As muscle metabolism increases to meet work demands, the rate of energy conversion from chemical energy to kinetic energy increases. Because the energy conversion from chemical energy to kinetic energy is inefficient, increased metabolism results in increased rates of heat gain to the person. The rate of metabolism depends directly on the rate and type of external work demanded by the job.

W—EXTERNAL WORK RATE

W is the amount of energy that is successfully converted from internal chemical energy to mechanical work on external objects. This route of energy transfer is called external work and it does not contribute to body heat. The rate of external work depends directly on forces applied against external resistance and distance moved. W is usually about 10 percent of M.

R—RADIANT HEAT EXCHANGE RATE (RADIATION)

Solid bodies of different temperatures have a net heat flow from the hotter surface to the cooler surface by electromagnetic radiation (primarily infrared radiation). The rate of heat transfer by radiation depends on the average temperature of the surrounding solid surfaces, skin temperature and clothing.

C—CONVECTIVE HEAT EXCHANGE RATE (CONVECTION)

The exchange of heat between the skin and the surrounding air is referred to as convection. The direction of heat flow depends on the temperature difference between the skin and air. If air temperature is greater than skin, C is positive and heat flows from the air to the skin. If the air is cooler than the skin, C is negative and heat flows from the body. The rate of convective heat exchange depends on the magnitude of the temperature difference, the amount of air motion, and clothing.

K—CONDUCTIVE HEAT EXCHANGE RATE (CONDUCTION)

When two solid bodies are in contact, heat will flow from the warmer body to the cooler body. The rate of heat transfer depends on the difference in temperatures between the skin and the solid surface, the thermal conductivity of the solid body that the person contacts, and clothing that may separate the person from the solid surface.

C_{RESP}—RATE OF CONVECTIVE HEAT EXCHANGE BY RESPIRATION

The fact that air is moved in and out of the lungs, which have a large surface area, means there is an opportunity to gain or lose heat. The rate of heat exchange depends on the air temperature and volume of air inhaled.

E_{RESP}—RATE OF EVAPORATIVE HEAT LOSS BY RESPIRATION

The large surface area of the lungs provides an opportunity to lose heat by evaporation. The rate of heat exchange depends on the air humidity and volume of air inhaled.

E—RATE OF EVAPORATIVE HEAT LOSS

Sweat on the skin surface will absorb heat from the skin when evaporating into the air. The process of evaporation cools the skin and in turn the body. The rate of evaporative heat loss depends on the amount of sweating, air movement, ambient humidity, and clothing.

Because *W, K,* C_{resp} and E_{resp} are small relative to the other routes of heat exchange in industrial applications, they are usually ignored. When calculating heat storage, Equation 1 becomes Equation 2 as a general statement of heat balance.

$$S = M + R + C + E \tag{2}$$

Excessive heating or cooling of a small portion of the skin can occur when it comes in contact with a hot or cold surface. The contact can be either intentional or incidental. Injury occurs when there is sufficient heat gain to cause a burn or heat loss to cause the tissue to freeze (or at least become very cold for a period of time). In these cases, the local storage rate (S_{local}) becomes important.

$$S_{local} = K + D \tag{3}$$

where *K* is conductive heat transfer between the skin and an object, and *D* is the rate of heat transfer to or from the local area by conduction through the local tissue and by the heat supplied or removed via local blood flow.

Factors Affecting Thermal Balance

As mentioned at the beginning of the discussion on thermal balance, three factors play an important role. They are the climatic conditions of the environment, work demands, and clothing. Climatic conditions are widely used to describe the degree of stress, as seen in casual descriptions by air temperature, relative humidity, and wind chill. They are not the only determinant of thermal stress.

The role of metabolic rate in heat balance is very important because it is a substantial contributor to heat gain. In heat stress, metabolic rate can add 10 to 100 times more heat to the body than radiation and convection combined. In cold stress, metabolic rate affects heat balance on the same order as radiation and convection losses.

Clothing is also a major contributor to thermal balance. Clothing has three characteristics: insulation, permeability, and ventilation.

Insulation is a measure of the resistance to heat flow by radiation, convection, and conduction. The greater the amount of insulation, the less the rate of heat flow from the warmer temperature to the cooler temperature. During heat stress exposures, it reduces heat flow by radiation and convection. It also reduces heat flow by conduction if a person has a substantial portion of the body in contact with a warm surface. Insulation plays a very important role (1) in preventing burns by contact with a hot surface and (2) in cold stress. In cold stress, it is used to reduce heat losses by convection and radiation as well as conduction, and it prevents cold injury to local tissues in contact with cold surfaces.

Permeability is a measure of the resistance to water vapor movement through the clothing. It is a factor in thermal stress because it influences the amount of evaporative cooling that can be achieved. Permeability is related to both insulation characteristics and the clothing fabrics. Generally, as insulation increases, permeability decreases. In addition, some clothing fabrics designed as a contamination barrier can reduce the magnitude of permeability. This means that there may actually be a trade-off between the risks of heat stress and the risks from skin contact with harmful chemicals. New protective clothing fabrics are entering the market that provide protection against some chemical hazards while permitting water vapor transmission. These new fabrics provide a greater range of opportunity to find a balance between prevention of chemical exposure and prevention of heat stress.

Clothing ventilation is the third factor. Depending on the nature of the fabric, garment construction, and work demands, ambient air can move through the fabric or around the garment openings. Clothing ensembles that support the movement of air can enhance evaporative and convective cooling; while those that are designed and worn to limit such movement, limit evaporative and convective cooling. A good example of using ventilation characteristics to regulate heat balance is arctic parkas with drawstrings around the waist, cuffs, and hood. As metabolism heats a person, cooling can be achieved by loosening some of the closures to increase the amount of air flow (ventilation) under the clothing.

HEAT STRESS

Remembering that thermal stress is a combination of environmental, work, and clothing factors, heat stress is a combination that tends to increase body temperature, heart rate, and sweating. These physiological adaptations are collectively known as heat strain. Figure 12–1 is a schematic representation of the physiological responses to heat stress.

Looking first at metabolism, the heat generated by muscular work heats the deep body tissues, which means that there is a tendency for core temperature to increase. Blood circulating through the core picks up heat energy, and the

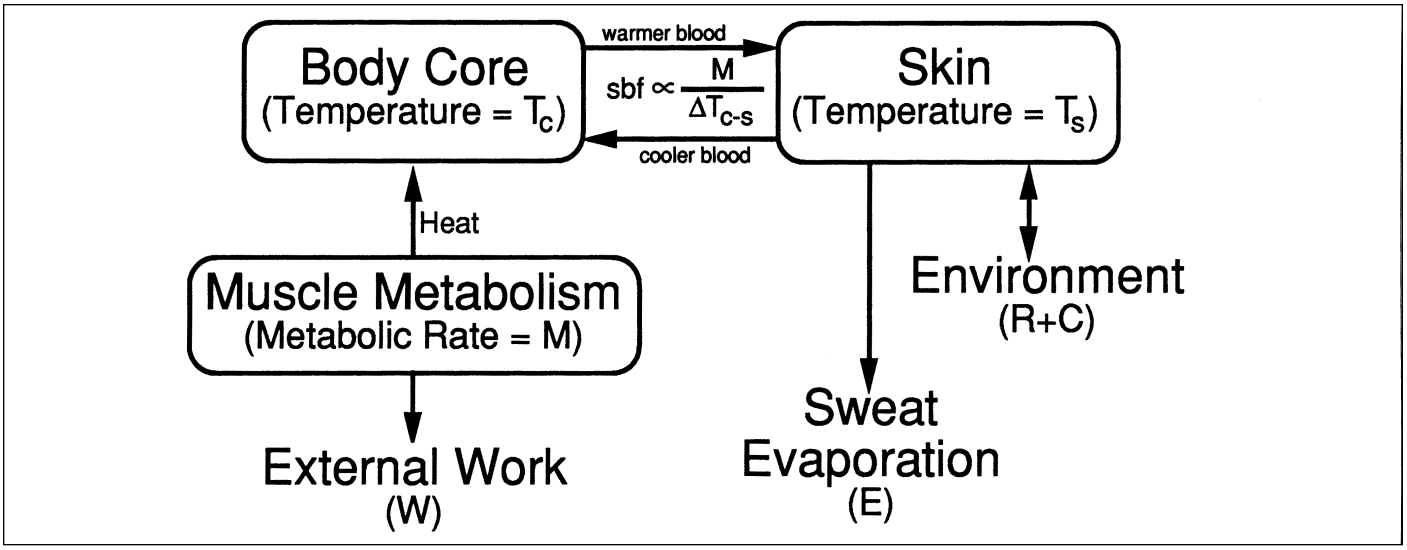

Figure 12–1. Heat flow through the body, beginning with heating the body core by metabolism, the transfer of heat by blood flow to the skin, heat gain or loss to the skin from the environment by radiation and convection, heat loss by sweat evaporation, and cooler blood returning to the core. Skin blood flow (sbf) to promote heat transfer is proportional to metabolic rate (M) divided by the difference between core and skin temperatures (ΔTc-s). (Adapted from T. E. Bernard, et al., *Heat Stress Management Program for Power Plants*, Electric Power Research Institute, NP4453L, 1991.)

warmer blood is directed to the skin where the blood is cooled. The cooler blood returns to the core to pick up more heat energy. The skin is the site of heat exchange with the environment. Convection and radiation depend on temperature differences between the skin and the environment; and the net heat exchange by $R+C$ can be either positive (heat gain) or negative (heat loss). In addition, the skin secretes sweat onto the surface. As the water evaporates, it removes more heat energy from the skin, cooling the skin surface. Under ideal conditions, the body balances heat gains with losses so that the storage rate, S, is zero. This is accomplished by increasing the sweating rate until evaporative cooling is sufficient to remove the heat generated by metabolism plus any heat gained from (or lost to) the environment through $R + C$. The required evaporative cooling is denoted as E_{req}. (Remember that the value of E_{req} is negative because heat flow is away from the body.) Then Equation 2 becomes

$$E_{req} = -(M + R + C) \quad (4)$$

Thus, E_{req} marks the degree of physiological adjustment required to establish a thermal equilibrium between the body and the environment so that the body does not store heat. In many heat stress exposures, M is the dominant term, and E_{req} increases to meet additional cooling requirements of the work demands.

Heart rate is another important physiological parameter in assessing heat strain because it reflects the demands on the cardiovascular system to move blood (and heat) from the core to the skin. The total blood flow through the heart is proportional to the metabolic rate and inversely proportional to the temperature difference between the core and the skin. As work demands and metabolic rate increase, cardiac output increases, as seen in the heart rate. Sometimes skin temperature increases because evaporative cooling is limited or the net heat gain from $R + C$ is high. As the skin temperature increases toward core temperature, more blood must be delivered to the skin to achieve the same rate of cooling.

Finally, sweat rate (and total sweat volume) is another important measure of physiological strain. The greater the level of heat stress, the greater is the sweat loss. The body has a natural ability to increase the tolerance to heat stress exposures through a process called acclimation (sometimes called acclimatization). As people become acclimated, they are able to sweat more and therefore increase their cooling capability. With increased cooling, heart rate and core temperature are lower for the same work conditions.

The following material on heat stress describes recognition, evaluation, and control of heat stress as it may affect the whole body. At the end, there is information on special topics including contact with hot surfaces and breathing of hot air.

Recognition of Heat Stress

Heat stress in the workplace can be recognized in terms of workplace risk factors and in terms of the effects it has on workers. The workplace risk factors, broadly stated, are hot environments, high work demands, and protective clothing requirements. These factors are the traditional considerations in the evaluation of heat stress, and the details are in the section on evaluation of heat stress. In essence, if the workplace is generally considered as being hot through subjective judgment of workers and supervisors, then heat stress may be present. If the demands for external work are high (e.g., high metabolic rate), heat stress may be a factor in environments that are considered comfortable by casual observers (those

Table 12–A. *Heat-Related Disorders Including the Symptoms, Signs, Causes, and Steps for First Aid and Prevention*

Disorder	*Symptoms*	*Signs*	*Cause*	*First Aid*	*Prevention*
Heat stroke	Chills Restlessness Irritability	Euphoria Red face Disorientation Hot, dry skin (usually, but not always) Erratic behavior Collapse Shivering Unconsciousness Convulsions Body temperature ≥104 F (40 C)	Excessive exposure Subnormal tolerance (genetic or acquired) Drug / alcohol abuse	Immediate, aggressive, effective cooling. Transport to hospital. Take body temperature.	Self-determination of heat stress exposure. Maintain a healthy life-style. Acclimation.
Heat exhaustion	Fatigue Weakness Blurred vision Dizziness, headache	High pulse rate Profuse sweating Low blood pressure Insecure gait Pale face Collapse Body temperature: Normal to slightly increased	Dehydration (caused by sweating, diarrhea, vomiting) Distribution of blood to the periphery Low level of acclimation Low level of fitness	Lie down flat on back in cool environment. Drink water. Loosen clothing.	Drink water or other fluids frequently. Add salt to food. Acclimation.
Dehydration	No early symptoms Fatigue / weakness Dry mouth	Loss of work capacity Increased response time	Excessive fluid loss caused by sweating, illness (vomiting or diarrhea), alcohol consumption	Fluid and salt replacement.	Drink water or other fluids frequently. Add salt to food.
Heat syncope	Blurred vision (gray-out) Fainting (brief black-out) Normal temperature	Brief fainting or near-fainting behavior	Pooling of blood in the legs and skin from prolonged static posture and heat exposure	Lie on back in cool environment. Drink water.	Flex leg muscles several times before moving. Stand or sit up slowly.
Heat cramps	Painful muscle cramps, especially in abdominal or fatigued muscles	Incapacitating pain in muscle	Electrolyte imbalance caused by prolonged sweating without adequate fluid and salt intake	Rest in cool environment. Drink salted water (0.5% salt solution). Massage muscles	If hard physical work is part of the job, workers should add extra salt to their food.
Heat rash (prickly heat)	Itching skin Reduced sweating	Skin eruptions	Prolonged, uninterrupted sweating Inadequate hygiene practices	Keep skin clean and dry. Reduce heat exposure.	Keep skin clean and periodically allow the skin to dry.

Note: Salting foods is encouraged as both treatment and prevention of some heat-related disorders. Workers on salt-restricted diets must consult their personal physicians.

not exerting themselves in the environment). Clothing is the third factor. While light-weight, loose-fitting, cotton clothing is the ensemble of choice during exposures to heat stress, many workplaces require protective clothing that decreases permeability and ventilation and increases insulation. The added weight of personal protection may increase the metabolic heat load and therefore the level of heat stress.

The responses of workers are a good tool for the recognition of heat stress in the workplace. At the extreme end are a pattern of heat-related disorders. Intermediate markers are physiological adjustments and worker behaviors.

HEAT-RELATED DISORDERS

Heat-related disorders are manifestations of over-exposures to heat stress. Table 12–A is a list of common or important heat-related disorders. The table includes the signs a trained observer may see, the symptoms the person may report, the likely cause of the disorder, first aid, and steps for prevention. Figure 12–2 is a simple illustration of normal responses to heat stress and how these responses may lead to a heat-related disorder.

Heat stroke is the most serious heat-related disorder. While it may be relatively rare, it must be immediately recognized and treated to minimize permanent damage. The risk of death is high in heat stroke. Heat exhaustion is the most commonly seen disorder when treatment is sought. Dehydration is a precursor to heat exhaustion, but it is usually not noticed or reported by workers.

As part of the recognition process, the health and safety professional examines reports to a medical or first aid facility. Because no specific heat-related disorders are listed does not

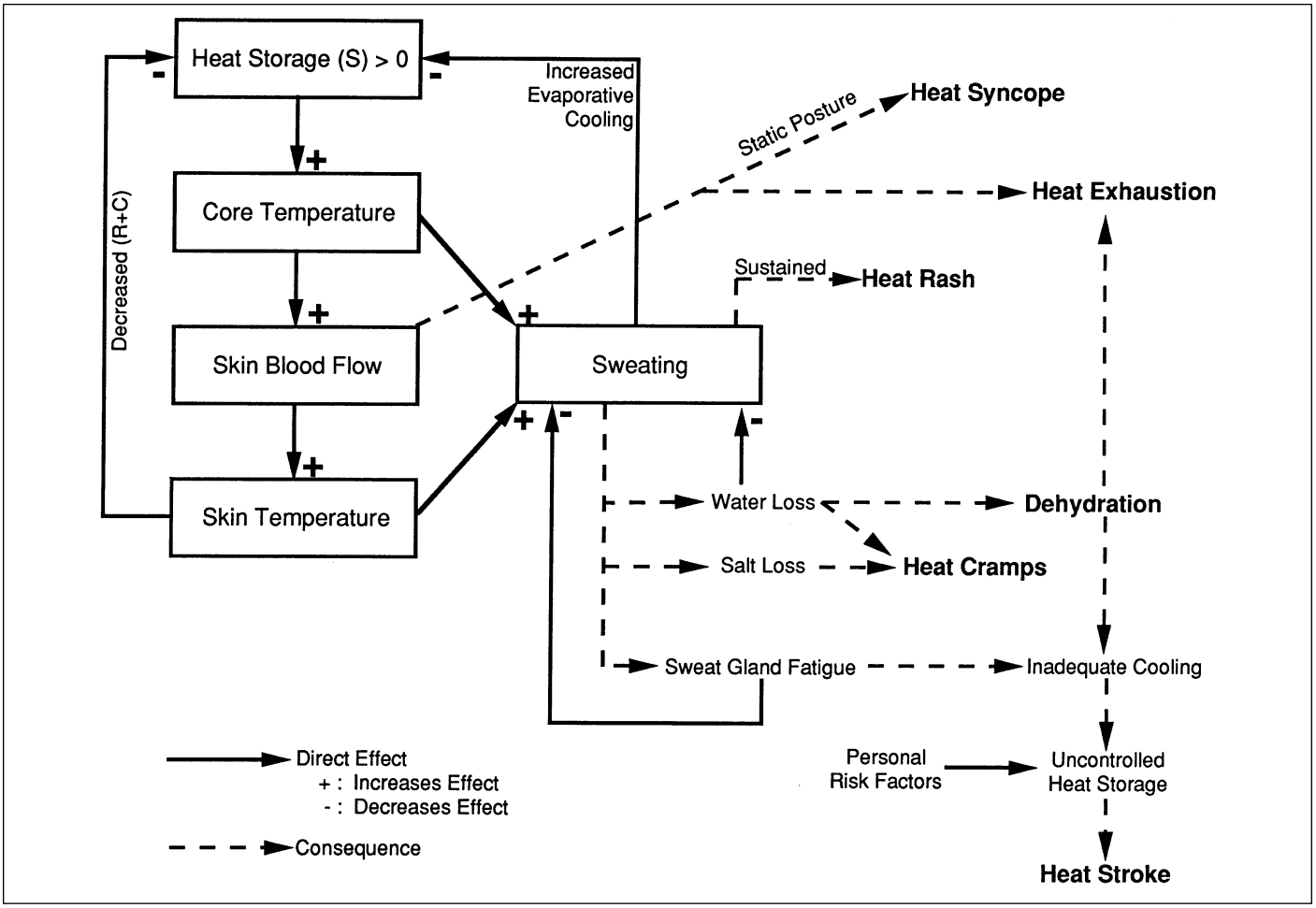

Figure 12–2. Normal responses to heat stress exposures and how they can lead to heat-related disorders.

mean heat stress is not present. It is worthwhile to examine the records for reports of faintness, weakness, nausea, cramps, headaches, and skin rashes. If temperatures are taken, some may be elevated. If urine samples are taken, some may have high specific gravity due to dehydration. There may also be an increase in the number of accidental injuries that are related to heat stress conditions.

PHYSIOLOGICAL MARKERS

Physiological responses to heat exposures can be used as a recognition tool. The most readily accessible are oral temperature, heart rate, and water loss. By noting one or more physiological responses of members of the work force, the health and safety professional can begin to see if a more detailed evaluation is necessary. When selecting workers to sample, it is important not to be biased toward those that appear to be the most tolerant. The sampling process should be random or favoring those who appear to be having more problems (see behaviors below).

While rectal, esophageal, and tympanic temperatures are the preferred measures of core temperature, oral temperature has long been used as an indicator of core temperature in industrial environments. Oral temperature can be measured by a traditional mercury-in-glass thermometer as well as an electronic version and disposable strips. (A caution using oral temperatures is that the person should not eat or drink for 15 minutes prior to taking the temperature and the person must keep the mouth closed.) Core temperature is estimated by adding 0.5 C or 1 F to the measured value of oral temperature. If core temperature is above 38 C (100.4 F), then heat stress is high enough to warrant evaluation.

Heart rate can be estimated by palpation of an artery near enough the surface that the pulse can be felt by the finger tips. There are also devices that can measure heart rate using electronic means. Among heart rate methods, recovery heart rate is most useful as a tool for recognition. Recovery heart rate methods require that the person stop in at the end of a work cycle, sit down, and determine the pulse rate at a given point in recovery. One method of recovery heart rate proposes that the heart rate at 1 min after sitting down be at or below 110 beats per minute (bpm). Another method recommends that the heart rate at three minutes be below 90 bpm. If either of these circumstances does not exist then the work including the heat stress may be excessive and an evaluation is appropriate.

Because there are devices for measuring and logging heart rate readily available, finding the average heart rate over an eight-hour day is reasonable. If the average heart rate over a day is greater than 110 bpm, the work and heat stress may be excessive. Examination of the log for peak heart rates is also informative. If heart rates are above a nominal threshold of 160 bpm, then the demands of the work should be evaluated. (For individually set thresholds, see physiological methods for evaluation below.)

Monitoring dehydration is a third means of recognizing potential heat stress conditions. This is accomplished by noting the change in body weight from the beginning to the end of a shift. If there is more than 1.5-percent loss of body weight, then excessive dehydration is likely and an evaluation is appropriate.

WORKER BEHAVIORS

Heat stress not only induces physiological changes but affects behavior. Likely behaviors associated with heat stress are actions that reduce exposures such as adjusting the clothing to increase evaporative losses, slowing the work rate or taking small breaks to lower the metabolic rate, and taking short cuts in work methods. Attitudes are reflected in irritability, low morale, and absenteeism. There is also an increased number of errors and machine breakdowns, and the frequency of unsafe behaviors increases.

SUMMARY OF RECOGNITION

Basically, there are four questions you may ask to determine whether the work conditions should be evaluated for heat stress.

1. Is the environment recognized as being hot, are the work demands high, or is protective clothing required?
2. Are worker behaviors indicative of attempts to reduce heat stress, is morale low or absenteeism high, or are people making mistakes or getting hurt?
3. Do the medical records show a pattern of fatigue, weakness, headache, rashes, or high body temperature?
4. Are body temperature, heart rate, or sweat losses high on a sample of workers?

When the answers to any of these questions is "yes", an evaluation is probably in order.

Evaluation of Heat Stress

In 1969, the World Health Organization (WHO) set the tone for worker protection against heat stress. One recommendation centers around body core temperature, which may be estimated from oral temperature as described in the discussion above on physiological markers. Core temperature should not exceed 38 C (100.4 F) during prolonged daily exposures to heat stress. The panel did recognize that 39 C (102.2 F) is acceptable as an upper limit for short periods followed by an adequate recovery and that the average heart rate over a day should not exceed 110 bpm. It is the prolonged daily exposure goal that is the foundation of evaluation schemes proposed by the National Institute for Occupational Safety and Health (NIOSH) in a 1986 criteria document and the basis for heat stress assessment as described by the American Conference of Governmental Industrial Hygienists (ACGIH) in earlier TLVs®.

Prolonged daily exposures to heat stress are evaluated assuming that the work conditions are prevalent for a full eight hours with nominal breaks. Often, the heat stress exposure may be more episodic. In this case, heat stress is evaluated in terms of safe exposures times for a given level of heat stress. The safe exposure times are prescribed through work-rest cycles based on prolonged daily exposure criteria or through heat-balance analyses. The methods to evaluate heat stress require at least an assessment of metabolic rate and some measures of the thermal environment. Some methods assume one kind of clothing and others have provisions for different ensembles.

Evaluation of workplace heat stress can also be accomplished by demonstrating that there is not an excessive physiological strain in the work force. That is, the exposure is less important in the evaluation than the dose or the outcome. First, an overview of the current ACGIH TLV® for heat stress and strain is provided to set the stage for the evaluation of occupational exposures to heat stress. This is followed by a discussion of methods to assess metabolic rate and environmental conditions. Methods to evaluate chronic and time-limited exposures to heat stress and methods to evaluate physiological strain are described in this section.

OVERVIEW OF ACGIH TLV® FOR HEAT STRESS AND STRAIN

The current ACGIH TLV for Heat Stress and Strain® (2000) recognizes the differences between eight-hour and short-duration exposures, and the value of physiological monitoring in the evaluation and control of heat stress. A flowchart in the TLV® guides the thought process for the evaluation of heat stress and strain (see Figure 12–3). The flow chart is entered at the top when heat stress is suspected in the workplace.

The first decision centers around the kind of clothing that may be worn. If the clothing is likely to substantially reduce evaporative cooling, then the usual means to evaluate heat stress do not apply and heat strain monitoring is the most feasible approach for evaluation. Not only vapor-barrier clothing restricts evaporative cooling, but multiple layers and some other materials may have high vapor resistances (low permeability).

The second decision is a simple screening test. Using available information on WBGT in the environments and the work demands (Figure 12–4), a table of WBGT limits for broad categories of work and work/rest proportions is provided. If the limits are not exceeded, then heat stress is low. On the other hand, exceeding the limits does not mean that the exposures are excessive. It means that a more detailed analysis is called for.

If the data are not available for a detailed analysis, then physiological monitoring is necessary. The detailed analysis requires a task analysis. From that information, time-

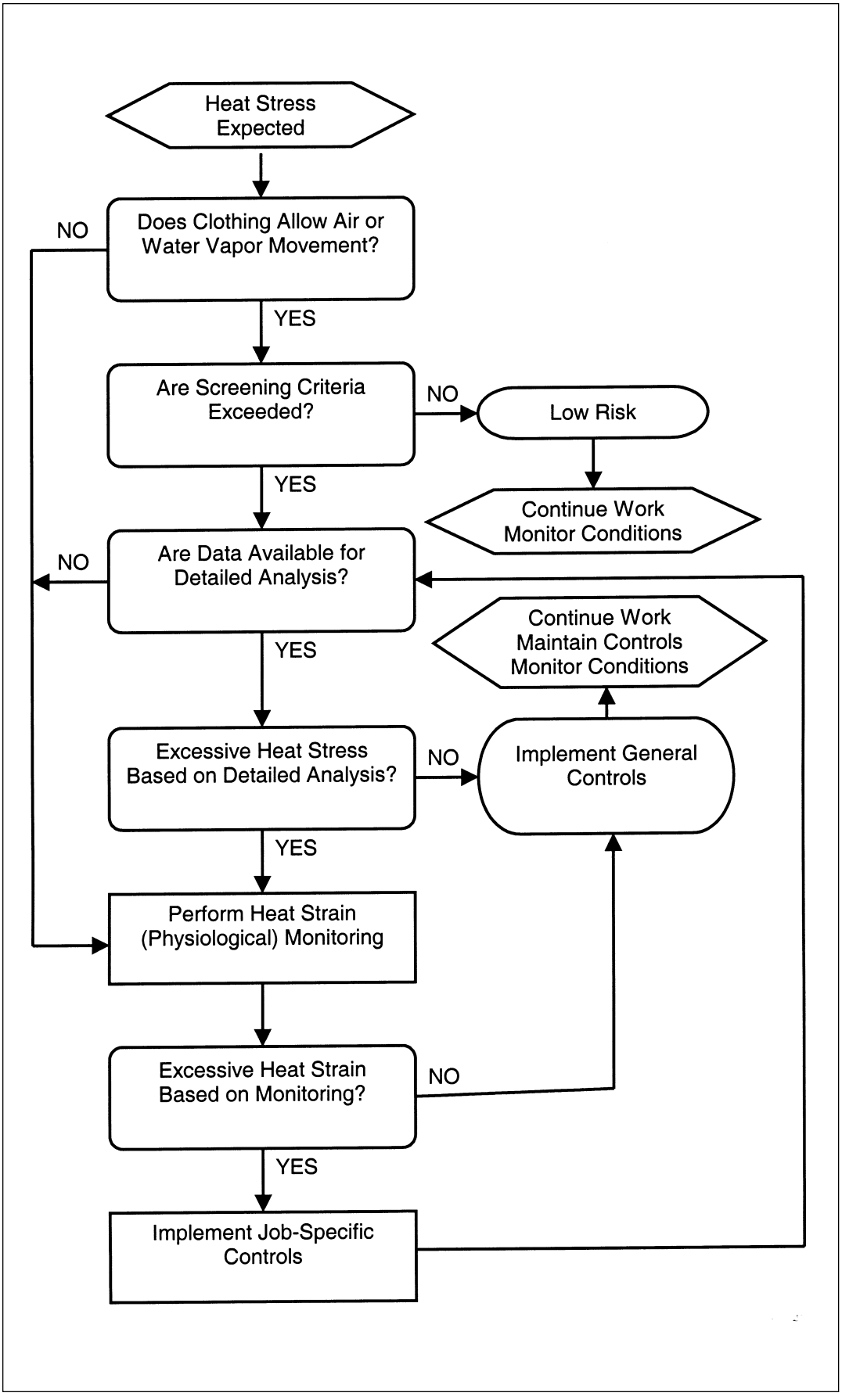

Figure 12–3. Flow chart for the ACGIH TLV® for heat stress and strain.

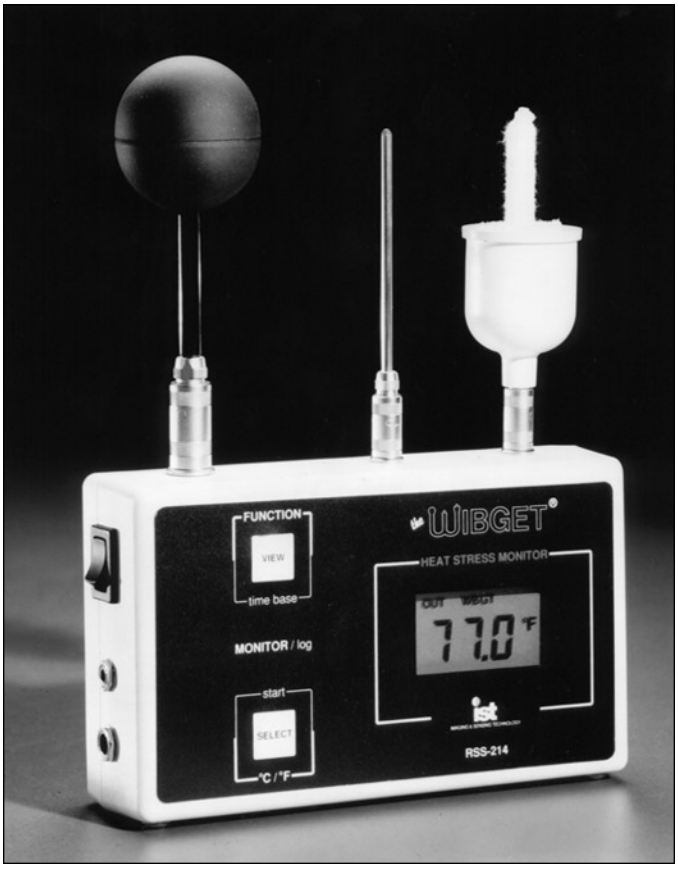

Figure 12–4. Examples of electronic devices used to measure WBGT. (Courtesy of Metrosonics, Inc., Quest Technologies, and IST.)

weighted averages of WBGT and metabolic rate can be compared to the TLV criteria (see Figure 12–5). In addition, a time-limited analysis using WBGT-based methods like the Navy PHEL (Figure 12–6) or like the heat balance analysis of Figure 12–7 can be done. If the exposures do not exceed the detailed analysis limits, then general controls should be implemented. If the exposures do exceed the time-limited criteria, then physiological monitoring is the next step.

No matter which route is taken to physiological monitoring, at least general controls are necessary. If these alone are associated with acceptable heat strain, then the analysis is complete. If there is excessive physiological strain, then job specific controls must also be implemented. Success is demonstrated when both general controls and job specific controls result in acceptable physiological strain.

ASSESSMENT OF METABOLIC RATE

Metabolic rate is the rate of internal heat generation, which must be dissipated from the body to maintain thermal equilibrium. (In cold stress, metabolic rate is important to maintain deep body temperature.) First, there is a base level of metabolism that is necessary to support life. Beyond basal metabolism, there is a work-driven metabolism that is largely due to muscular effort. The greatest amount of metabolism due to muscular effort

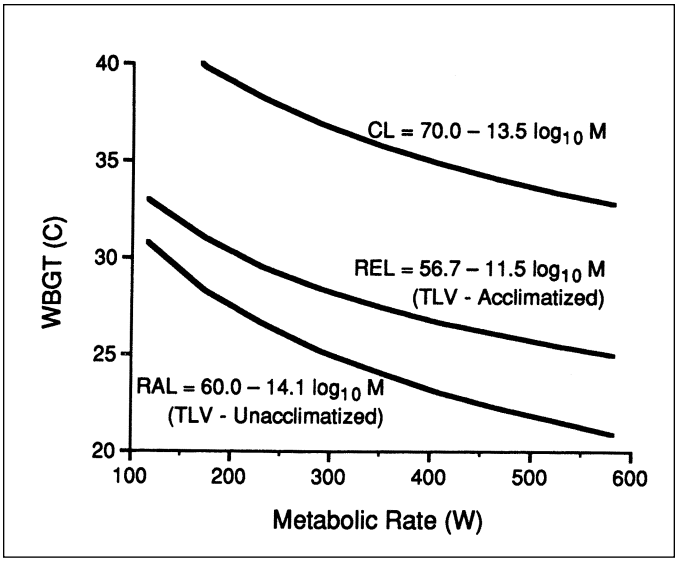

Figure 12–5. Heat stress limits proposed by NIOSH (Ceiling Limit/Ceiling, Recommended Exposure Limit/REL and Recommended Alert Limit/RAL) and ACGIH (TLV for Acclimatized Workers®/Acclimatized and TLV for Unacclimatized Workers®).

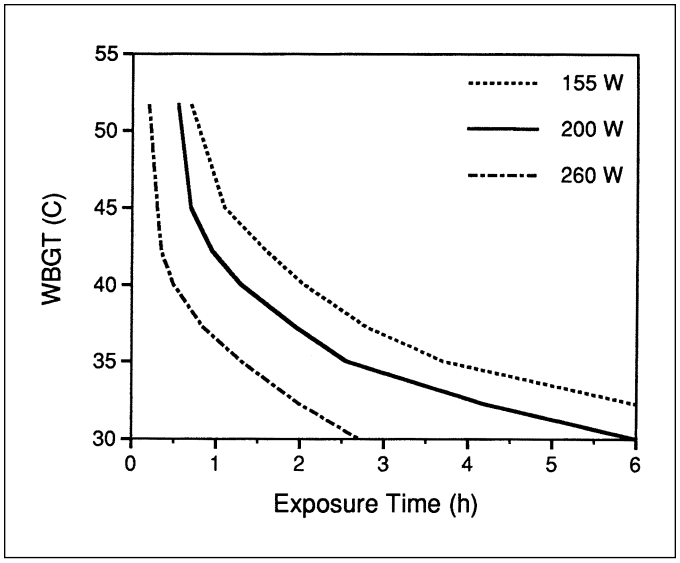

Figure 12–6. Example of U.S. Navy Permissible Heat Exposure Limit (PHEL) chart. Clothing is ordinary summer-weight work clothes.

occurs when the muscles exert a force with motion (dynamic work), and much less metabolism is required to exert a force with no motion (isometric contraction or static work). Therefore, the greatest metabolic rates occur when the body must be moved over a distance, especially upwards, and when objects are moved in space. Lesser metabolic rates are seen for sedentary activities or simply holding objects without any motion.

One very simple method to assess metabolic rate is to assign the work demands into one of three to five categories of metabolic rate (e.g., light, moderate, heavy). Another simple method is to look for similar activities in published tables of metabolic rates for specific activities (or assume the demands are equivalent by subjective matching). Either of these methods are expedient, but not very accurate (and perhaps prone to over-estimation).

Some discipline is required in the assessment of metabolic rate. The first step is to divide the job into discrete, homogeneous tasks, and then determine their frequency and duration. Then a metabolic rate can be assigned to each task. Finally, the time-weighted average for metabolic rate can be determined (TWA-M®). Using categories or tables to assign values of metabolic rate to a task reduces some of the error, but the ISO method is recommended and outlined in the following paragraph. In addition there are other published methods that provide good results.

Following the ISO method for a given task, the metabolic rate can be estimated by summing together five components. The components are basal metabolism (B), posture (P), activity based on degree of body involvement (A), the horizontal travel (H) and vertical travel (V). That is,

$$M_{\text{task}} = B + P + A + H + V \qquad (5)$$

Table 12–B describes values of metabolic rate associated with each of the components. The SI units for metabolic rate are watts, and conversion factors to change from watts to units reported in other sources (i.e., kcal/min, kcal/h, Btu/h, L/min of oxygen consumption) are provided at the bottom.

ASSESSMENT OF THE ENVIRONMENTAL CONDITIONS

The environmental factors that are central to the assessment of heat stress are air temperature, humidity, air speed, and average temperature of the solid surroundings. How these factors are incorporated into the evaluation of heat stress depend on the evaluation tool. The SI unit for temperature is degrees Centigrade.

Dry bulb temperature (T_{db}) is the direct measure of air temperature. The temperature sensor is surrounded by air, which is allowed to freely flow around the sensor. The sensor, however, may be influenced by radiant heat sources and therefore should be shielded from them.

Psychrometric wet bulb temperature (T_{pwb}) is based on the degree of evaporative cooling that can occur. In practice, a wetted wick is placed around a temperature sensor and enough air is forced over the wick to maximize the rate of evaporative cooling (> 3 m/s). The amount of temperature reduction that can be achieved depends directly on the amount of water vapor in the air. When humidity is high (high water-vapor pressure), the reduction in temperature is low. When the humidity is lower, the reduction is higher.

Ambient water vapor pressure (P_v) is commonly known as humidity. There are two ways humidity is expressed—*relative* and *absolute*. At any given temperature, the partial pressure of water vapor that can be in the air has a maximum value, the saturation pressure. At low temperatures, the

Table 12–B. *Values for the Four Components of Equation 5 to Estimate the Metabolic Rate for a Task (in watts)*

		Average (watts)	Range (watts)
Basal metabolism (B)		70	
Posture metabolism (P)			
Sitting		20	
Standing		40	
Walking		170	140–210
Activity (A)			
Hand	light	30	15–85
	heavy	65	
One arm	light	70	50–175
	heavy	120	
Both arms	light	105	70–245
	heavy	175	
Whole body	light	245	175–1,050
	moderate	350	
	heavy	490	
	very heavy	630	

Walking (H)
H_{hor} = rate of horizontal travel (meters/min)
$H = 3.3\ H_{hor}$
Climbing (V)
V_{vert} = rate of vertical ascent (meters/min)
$V = 56 V_{vert}$

Unit Conversions for Metabolic Rate

From Watts to Other Units	From Other Units to Watts
kcal/min = 0.014 × W	W = 70 × kcal/min
kcal/h = 0.86 × W	W = 1.2 × kcal/h
Btu/h = 3.4 × W	W = 0.29 × Btu/h
l O_2/min = 0.0029 × W	W = 350 l × O_2/min

Note: Values are based on a person weighing 70 kg.

saturation pressure is low, and it increases exponentially with temperature. Relative humidity is the ratio of the water vapor pressure in the air to the saturation pressure at that temperature. So 50 percent relative humidity means that the water vapor pressure is 50 percent of the saturation pressure. Unfortunately, relative humidity is not very useful as a tool to assess heat stress because the water vapor pressure represented by a value of relative humidity can be radically different depending on the air temperature. Absolute humidity is expressed as the amount of water vapor in the air in terms of partial pressure or weight per unit volume of air. The usual practice for heat stress evaluation is to use the partial pressure and the SI unit is kPa (kiloPascals). (To convert from kPa to mmHg, the value in kPa is multiplied by 7.5.) Usually a psychrometric chart is used to determine humidity from T_{db} and T_{pwb}. Figure 12–7 provides an equation to estimate water vapor pressure from these temperatures.

Natural wet bulb temperature (T_{nwb}) is similar to the psychrometric wet bulb except that air is allowed to flow over the sensor naturally rather than being forced. When air flow is less than 3 m/s, the temperature reduction is less than psychrometric wet bulb for the same absolute humidity. That is, natural wet bulb temperature is sensitive to both humidity and air movement.

Air speed (V_{air}) is measured using an appropriate anemometer. The anemometer should not be unidirectional. Because the speed will vary in space and time, an average value is used.

Globe temperature (T_g) responds to radiant heat from the solid surroundings and convective heat with the ambient air. The globe temperature is classically measured using a six-inch, thin-walled, copper sphere, painted matte black on the outside. The temperature sensor is placed at the center of the globe. When all the surrounding surfaces are the same temperature as the air, the globe temperature is equal to air temperature. If one or more of the surfaces are different, then the globe temperature will increase or decrease depending on the average temperature of the solid surroundings. Finally, for a given level of radiant heat exchange with the globe, the globe temperature will differ the most from air temperature with little air movement, and will differ the least with a significant air motion because it is also sensitive to convective heat exchange with the air. Globe temperature is used to estimate the average wall temperature of the surroundings.

Effective Temperature (ET) and *Corrected Effective Temperature (CET)* are indices of the thermal environment that were first developed to equate thermal sensation, and later used to describe thermal stress. *ET* is determined from a nomogram that requires knowledge of T_{db}, T_{pwb}, and V_{air}. For a sedentary person dressed in light clothing, equal values of *ET* would indicate similar sensations of warmth. Because of its history, it was used in the early studies of heat stress as an index of the environment.

Because *ET* did not account for radiant heat, *CET* was proposed. It uses T_g instead of T_{db} when entering the nomogram.

Neither *ET* nor *CET* is used to evaluate heat stress today. Instead a new index was required that could be more easily determined and was indicative of thermal stress from the environment. The wet bulb globe temperature was the evolutionary step from *ET* and *CET*.

Wet bulb globe temperature (WBGT) is an index of environmental heat that is widely used to evaluate industrial heat stress. In environments that are inside, in the shade, or on a cloudy day, it is computed as

$$WBGT_{in} = 0.7\,T_{nwb} + 0.3\,T_g \quad (6)$$

Under conditions of direct sun light (outdoors and no cloud cover), it is computed as

$$WBGT_{out} = 0.7\,T_{nwb} + 0.2\,T_g + 0.1\,T_{db} \quad (7)$$

Instrumentation to assess WBGT was originally a large copper globe and mercury-in-glass thermometers. There are several manufacturers of electronic instrumentation and they often use smaller globes. In addition to computing the WBGT directly, some can perform data logging functions as

well as real-time analysis of the environment (e.g., safe work times). The electronic instrumentation has virtually replaced the conventional WBGT "Christmas tree apparatus." (See Figure 12–4.)

EVALUATION OF PROLONGED EXPOSURES TO HEAT STRESS

With a goal of limiting the heat stress dose (core temperature not to exceed 38 C or 100.4 F), the problem becomes one of relating exposure (combinations of environment, metabolism, and clothing) to dose. Lind proposed the concept of the upper limit of the prescriptive zone (Bernard et al, 1994). In a set of classic experiments he demonstrated several important relationships between work, environment, and core temperature. In essence, he found that for a given metabolic rate, core temperature would remain relatively constant for increasing levels of environmental heat until a critical level. Then the core temperature would steeply rise with increasing levels of environmental heat, creating an increased risk for heat disorders. This critical level of heat stress was the upper limit of the prescriptive zone, and the person could work eight hours at or below this level without significant risk of a heat disorder. The upper limit is at lower levels of environmental heat for higher metabolic rates, and vice versa.

By exploring the upper limit of the prescriptive zone for different worker populations, Dukes-Dobos developed protective limits for the 95th percentile of the general worker population. At these protective limits, core temperature should not exceed 38 C (100.4 F) and first-minute recovery heart rates should not exceed 110 bpm. The upper limit of the prescriptive zone was first adapted by NIOSH in 1972 and revised in 1986. It was adopted by the ACGIH in 1973 (and revised in 1990) for the TLV for Heat Stress®. The International Organization for Standardization (ISO) also adapted the NIOSH thresholds in 1983. The limits are expressed in hourly time-weighted averages for both the WBGT and metabolic rate. The thresholds are illustrated in Figure 12–5 using both the NIOSH and ACGIH nomenclature.

The middle curve is called the *Recommended Exposure Limit* (*REL*) by NIOSH. For workers wearing ordinary cloth summer-weight work clothes and who are acclimated to heat, there should be practically no risk of heat-related disorders when working for eight hours with nominal breaks every two hours. Notice that as the metabolic rate increases, the threshold for WBGT decreases. This means that to maintain core temperature below 38 C (100.4 F) requires a "cooler" environment for higher internal heat generation. The ACGIH calls this threshold the TLV for Acclimatized Workers®.

The lower curve is called the *Recommended Alert Limit* by NIOSH and the TLV for Unacclimatized Workers® by the ACGIH. This curve is proposed in recognition that unacclimated workers are less able to tolerate heat-stress exposures and this lower tolerance can be accommodated by a lower level of environmental heat at the same work demands.

The upper curve is the *Ceiling Limit* proposed by NIOSH, but not included in the TLV®. An individual not wearing personal protection should not be exposed to this temperature level for more than 15 minutes.

Table 12–C. ***WBGT Adjustment Factors for Different Clothing Ensembles in Degrees C****

Clothing Type	*ACGIH*	*Other Sources*
Work Clothes	0	0
Coveralls	3.5	
Double Coveralls	5	
SMS Coveralls		–1
Tyvek® 1422A Coveralls		2
Vapor-Transmitting Water-Barrier		2 – 6
Vapor-Barrier		8
Encapsulating Suit		11

* The adjustment factors are added to the measured WBGT.

Because clothing is also a factor in determining the level of heat stress, the ACGIH has proposed a table of adjustment factors that can be added to the measured values of WBGT in the environments of interest. These are given in Table 12–C. Also included in the table are adjustment factors for other kinds of clothing that may be found in the workplace. An important note about using the adjustment factors is that they represent the current best guess about the effects of clothing other than ordinary work clothes, and some caution is necessary in using them. Using physiological strain indicators (i.e., personal monitoring) to confirm the evaluation may be appropriate.

To evaluate a job for heat stress, a one- to two-hour interval for time-weighted averaging must be selected. If the work is repeated in an hourly pattern, a one-hour TWA can be used. If the work is intermittent, a two-hour TWA may be more representative of the demands. TWA-M and TWA-WBGT must be calculated for the selected interval. Adjust the WBGT for each location by adding the clothing adjustment factor to the measured value as appropriate. With these TWA values, the work can be located in the graph of Figure 12–5. If it is below the RAL/TLV for unacclimatized workers, there is no practical risk for heat-related disorders to develop even for the least heat-tolerant but otherwise healthy workers. If it is between the RAL/TLV for unacclimatized workers and REL/TLV for acclimatized workers, then a program of heat-stress management should be in place. The program should include at least the general controls described in the section on controls. If it is above the REL/TLV for acclimatized workers, then heat stress is a hazard in the work environment and control actions should be taken.

EVALUATION OF TIME-LIMITED EXPOSURES TO HEAT STRESS

For heat-stress exposures above the REL/TLV, the question may become, how long can someone safely work? This question can be answered either by WBGT-based methods or by heat-balance analysis.

The following description of the ISO analysis of required sweat rate is divided into three sections. The first describes the steps in computing the individual terms of the heat balance equation (see Equation 1). The second section presents the criteria for unacclimated and acclimated workers at two levels of heat stress risk. The final section describes the computations for the time limit.

Computation of Heat Exchange

Adjust metabolic rate for body surface area. The following values of heat exchange are normalized to body surface area.

$$M = \frac{\text{Metabolic rate}}{1.8} \tag{1}$$

Adjust air velocity for work activities if $M > 58$. The method recognizes that air motion around the body results from both environmental conditions and body motion during work.

$$V = V_{air} + 0.0052\,(M - 58) \tag{2}$$

Limit the increase due to metabolism to 0.7 m/s (at M > 193 W/m^2) and V to 3.0 m/s.

Compute coefficient for convection. The convective heat exchange can be caused by either natural or forced convection. The greater value for natural or forced convection is used.

$$h_{cn} = 2.38\,(|T_{db} - 36|)^{0.25} \tag{3}$$

If $V \leq 1$ m/s, $h_{cf} = 3.5 + 5.2V$; if $V > 1$ m/s, $h_{cf} = 8.7V^{0.6}$

$$h_c = \text{Greater value of } (h_{cn}, h_{cf}) \tag{4}$$

Compute mean radiant temperature. The following equation computes the mean radiant temperature from globe temperature, recognizing that natural convection and air movement influence globe temperature.

$$\zeta = \text{Greater value of } \{0.4\,(|T_g - T_{db}|)^{0.25}, 2.5\,V_{air}^{0.6}\} \tag{5}$$

$$T_r = 100\left[\left(\frac{T_g + 273}{100}\right)^4 + \zeta\,(T_g - T_{db})\right]^{0.25} - 273 \tag{6}$$

Compute coefficient of radiation for a standing person. The rate of radiant heat exchange is lower for other postures.

$$h_r = 4.1 \times 10^{-8}\frac{(T_{sk} + 273)^4 - (T_r + 273)^4}{T_{sk} - T_r} \tag{7}$$

Compute clothing reduction factor for insulation. Because clothing insulation influences (reduces) the rate of heat transfer by radiation and convection with reference to a nude person, the reduction factor must be computed.

$$F_{cl} = \frac{1}{(h_c + h_r)\,I_{cl} + \dfrac{1}{(1 + 1.97I_{cl})}} \tag{8}$$

where I_{cl} is the clothing insulation ("clo" is a unit of clothing insulation: clo $\times$ 0.156 = m$^2 \cdot$ °C/W) For example,

$$\begin{aligned} &\text{light work clothes (reference: 0.6 clo) } 0.093 \text{ m}^2\ ^\circ\text{C/W} \\ &\text{coveralls (reference: 0.8 clo) } 0.125 \text{ m}^2\ ^\circ\text{C/W} \end{aligned} \tag{9}$$

Average skin temperature is often assumed to be between 35 and 36 C. It can also be estimated as

$$T_{sk} = 30.0 + 0.093\,T_{db} + 0.045\,T_r - 0.571\,V_{air} + 0.254\,P_a + 0.00128\,M - 3.57\,I_{cl} \tag{10}$$

Compute convective heat exchange.

$$C = h_c F_{cl}\,(T_{db} - T_{sk}) \tag{11}$$

Compute radiant heat exchange.

$$R = h_r F_{cl}\,(T_r - T_{sk}) \tag{12}$$

Compute required evaporative cooling.

$$E_{req} = -(M + C + R) \tag{13}$$

Compute clothing reduction factor for water vapor permeation for cotton clothing. Because clothing insulation influences (reduces) the rate of heat transfer by evaporation with reference to a nude person, the reduction factor must be computed.

$$F_{pcl} = 1 + 2.22\,h_c\left(\frac{I_{cl} - \left(1 - \dfrac{1}{1 + 1.97I_{cl}}\right)}{h_c + h_r}\right) \tag{14}$$

Compute ambient water vapor pressure (P_a). (An alternative is to determine this from a psychrometric chart.)

$$P_a = 0.6105\,\exp\frac{17.27\,T_{pwb}}{T_{pwb} + 237.3} - 0.0669\,(T_{db} - T_{pwb})(1 + 0.00115\,T_{pwb}) \tag{15}$$

To estimate T_{pwb} from T_{nwb},

$$T_{pwb} = T_{db} - \frac{T_{db} - T_{nwb}}{d} \tag{16}$$

where $d = 0.85$ if $V_{air} \leq 0.03$ m/s
$d = 1.00$ if $V_{air} \geq 3.0$ m/s
$d = 0.69 \log_{10} V_{air} + 0.96$ if $0.03 < V_{air} < 3.0$ m/s

Compute water vapor pressure on the skin. (An alternative is to get this from a psychrometric chart or tables.)

$$P_{sk} = 0.6105\,\exp\frac{17.27\,T_{sk}}{T_{sk} + 237.3} \tag{17}$$

Compute maximal evaporative cooling to the environment.

$$E_{max} = -16.7\,h_c F_{pcl}\,(P_{sk} - P_a) \tag{18}$$

Figure 12–7. Description of computational steps for the heat-balance analysis proposed by the International Organization for Standardization (ISO) for the evaluation of time-limited heat stress. Experimentally derived factors for F_{cl} and F_{pcl} for nonwoven fabrics have been proposed by Barker, Kini, and Bernard. ***(Continues)***

Compute required skin wetness. Skin wetness is the degree to which the skin is covered by water.

$$w = \frac{E_{req}}{E_{max}} \quad (19)$$

$$w_{req} = \text{Lesser value of } (w, 1.0) \quad (20)$$

Compute sweating efficiency. Because some water is lost by dripping, sweating efficiency depends on skin wetness.

$$\eta = 1.0 - \frac{(w_{req})^2}{2} \quad (21)$$

Compute required sweat rate.

$$SW_{req} = \frac{-E_{req}}{\eta} \quad (22)$$

Criteria. Select criteria by acclimation state and by heat strain level (warning or danger).

		Unacclimated		*Acclimated*	
Criteria	*Units*	*Warning*	*Danger*	*Warning*	*Danger*
SW_{max}	W/m^2	200	250	300	400
—	l/hr	0.52	0.65	0.78	1.04
w_{max}	—	0.85	0.85	1.0	1.0
Q_{max}	$W \cdot hr/m^2$	50	60	50	60
SV_{max}	$W \cdot hr/m^2$	1,000	1,250	1,500	2,000
—	l	2.5	3.25	3.9	5.2

Unacclimated: Workers have not had at least 5 days of 2-hour heat stress exposures over the preceding 7 days.

Acclimated: Workers have had at least 5 days of 2-hour heat stress exposures over the past 7 days.

Warning: If work time exceeds recommended time for Warning, controls should be considered. Adequate recovery should be allowed.

Danger: If work time reaches Danger time, controls are necessary.

*If $M < 65$, the $SW_{max} = 0.6\ SW_{max}$.

Once the criteria are selected, predicted values for skin wetness, evaporative cooling, and sweat rate can be determined.

If $w_{req} \leq w_{max}$ and $8SW_{req} \leq SV_{max}$, then the heat stress is not time limited.

Compute Condition A. The predicted values equal required values as follows:

$$w_p = w_{req} \quad (23)$$

$$E_p = E_{req} \quad (24)$$

$$SW_p = SW_{req} \quad (25)$$

If $w_{req} > w_{max}$, compute Condition B (time is limited by skin wetness).

$$w_p = w_{max} \quad (26)$$

$$E_p = w_p E_{max} \quad (27)$$

$$\eta_p = 1.0 - \frac{(w_p)^2}{2} \quad (28)$$

$$SW_p = \frac{-E_p}{\eta_p} \quad (29)$$

If $SW_{req} > SW_{max}$ from Condition A or $SW_p > SW_{max}$ from Condition B, compute Condition C, which is limited by sweat rate.

$$\phi = \frac{E_{max}}{SW_{max}} \quad (30)$$

$$w^*_p = (\phi + 2)^{0.5} - \phi \quad (31)$$

$$w_p = \text{Lesser value of } (w^*_p, w_{max}) \quad (32)$$

$$\eta_p = 1.0 - \frac{(w_p)^2}{2} \quad (33)$$

$$E_p = w_p E_{max} \quad (34)$$

$$SW_p = \frac{-E_p}{\eta_p} \text{ (which is usually } SW_{max}) \quad (35)$$

Compute time limit. The computed time limits are based on the ability to support a sufficient rate of evaporative cooling and on the risk of dehydration.

If Condition C was computed, use Condition C values to compute the time limit. If Condition C was not computed and Condition B was computed, use Condition B values to compute the time limit. If neither Condition B nor C was computed, use Condition A values to compute the time limit.

Evaporative cooling time limit.

$$t_e = \frac{60 Q_{max}}{E_p - E_{req}} \quad (36)$$

Sweat volume time limit.

$$t_d = \frac{60 SV_{max}}{SW_p} \quad (37)$$

Sweat rate for standard man (SR).

$$SR = 0.0026 SW_p \quad (38)$$

The ISO method is best computed on a personal computer using a spreadsheet or computational language such as BASIC or FORTRAN. A commercial software package developed by J. B. Malchaire, Heat Stress Evaluation, Version 2, is available from Lewis Publishers and other packages developed by individuals are also available.

Figure 12–7. ***(Concluded)***

Table 12–D. *Definition of Terms Used in Figure 12–7*

Term	*Description*	*Units*
M	Metabolic rate—normalized	W / m^2
SA	Body surface area	m^2
P_a	Ambient water vapor pressure	kPa
T_{pwb}	Psychrometric wet bulb temperature	C
T_{db}	Dry bulb (air) temperature	C
T_r	Mean radiant temperature	C
T_g	Globe temperature	C
V_{air}	Air speed	m / s
T_{sk}	Average skin temperature	C
I_{cl}	Clothing insulation	(m^2 • C) / W
V	Adjusted air speed	m / s
h_{cn}	Coefficient of convection—natural	W / (m^2 C)
h_{cf}	Coefficient of convection—forced	W / (m^2 C)
h_c	Coefficient of convection	W / (m^2 C)
h_r	Coefficient of radiation	W / (m^2 C)
F_{cl}	Clothing reduction factor	—
C	Convective heat exchange	W / m^2
R	Radiant heat exchange	W / m^2
E_{req}	Required evaporative cooling	W / m^2
F_{pcl}	Clothing reduction factor for water vapor permeation	—
P_{sk}	Water vapor pressure on skin	kPa
E_{max}	Maximum rate of evaporative cooling	W / m^2
w_{req}	Required skin wetness	—
η	Sweating efficiency	—
SW_{req}	Required sweat rate	W / m^2
SW_{max}	Maximum sweat rate	W / m^2
w_{max}	Maximum skin wetness	—
Q_{max}	Maximum heat storage	(W • hr) / m^2
SV_{max}	Maximum sweat loss	(W • hr) / m^2
w_p	Predicted skin wetness	—
E_p	Predicted rate of evaporative cooling	W / m^2
SW_p	Predicted sweat rate	W / m^2
SR	Sweat rate	l/h
t_w	Time limit based on skin wetness	min
t_d	Time limit based on dehydration	min
t	Time limit	min

WBGT techniques. WBGT techniques fall into two methods. One method uses TWAs and the TLV®. Then the question is asked in terms of how much time in an hour can someone work above the TLV compared to the time work or recovery is below the TLV? This first question is a general case of work-rest cycles. For the simple case of one work condition and one recovery condition refer to Figure 12–8. At work, Point A is at [TWA-M and TWA-WBGT]$_{work}$ and recovery (rest or light duty work) [TWA-M and TWA-WBGT]$_{recovery}$ is at Point C. Point B is at the intersection of the line A-C with the threshold line. The ratio of recovery time to heat stress exposure time is equal to the length of A-B to the length of B-C.

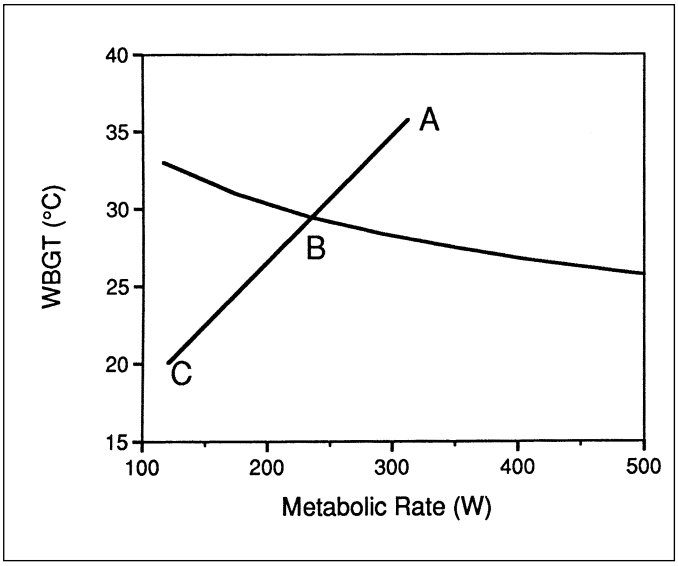

Figure 12–8. Graphical method to determine the ratio of recovery to exposure time. Point A is work conditions and Point C is recovery conditions. Ratio of rest time to work time is equal to length of A-B divided by length of B-C.

Another way to use the WBGT/TLV method is to iterate on a solution by testing various combinations of exposure time and recovery time that equal one hour so that the combination of TWA-M and TWA-WBGT lands on the TLV® line. (A spreadsheet solution can be developed by using the equation for the TLV line provided in the Figure 12–5.)

The U.S. Navy and the Electric Power Research Institute have proposed WBGT methods to determine safe exposures times from charts. An example of the Navy Permissible Heat Exposure Limit (PHEL) chart is illustrated in Figure 12–6 (clothing is ordinary summer-weight work clothes).

Heat-balance analysis. Heat balance analysis uses a model of heat exchange between a hypothetical person and the environment. While the WBGT methods mentioned previously are empirical methods of heat-stress evaluation, the method of heat-balance analysis is considered a rational method. If thermal equilibrium can be established, then there is no risk of an excessive level of heat stress. If thermal equilibrium cannot be established, then the amount of time to reach an upper limit of heat storage (nominally to

a core temperature of 38.5 C or 101.3 F) can be determined. That desktop evaluations of potential countermeasures can be performed is another advantage of heat balance analysis.

One method used by many industrial hygienists is called the Heat Stress Index (HSI) (proposed by Belding and Hatch). It starts from the premise that Equation 2 describes heat balance and Equation 4 describes the evaporative cooling requirements. Equation 4 is repeated here.

$$E_{req} = -(M + R + C) \tag{4}$$

The HSI is based on simple relationships for computing R and C, which have been updated over the years. The equations that follow are for workers wearing ordinary cloth work clothes and the units are watts, degrees C, meters per second (m/s) for air speed (V_{air}), and kiloPascals (kPa) for water-vapor pressure.

Basically, R is equal to a clothing-related constant times the difference between the mean temperature of the surroundings (T_r) and a mean skin temperature of 35 C (95 F). Obviously, if the average surrounding temperature is greater than skin temperature, there is a gain of heat by radiation.

$$R = 7.7\,(T_r - 35) \tag{8}$$

where

$$T_r = T_g + 1.8\,V_{air}^{0.5}\,(T_g - T_{db}) \tag{9}$$

C is equal to a clothing-related constant times a power function of air speed times the difference between air and skin temperature, as follows

$$C = 8.1\,V_{air}^{0.6}\,(T_{db} - 35) \tag{10}$$

If the air temperature is greater than skin temperature, there is a heat gain by convection; if skin temperature is less than air, there is a heat loss.

The method also provides for the determination of the maximum rate of evaporative cooling (E_{max}), which has either an environmental or physiological limit. The environmental limit on E_{max} is determined as a clothing-related constant times a power function of air speed times the difference between skin and air water-vapor pressure (P_v)

$$E_{max} = 122\,V_{air}^{0.6}\,(P_v - 5.6) \tag{11}$$

Because P_v is less than 5.6, E_{max} will have a negative value representing a heat loss. The physiological limit is based on a limiting sweat rate of 1 L/h, which is equivalent to a heat flow of –675 W. Therefore E_{max} is the greater negative number of that computed from Equation 6 or –675. Then

$$HSI = 100\frac{E_{req}}{E_{max}} \tag{12}$$

If the HSI is less than 40 then heat stress is low and no further actions are required. If the HSI is between 40 and 70, heat stress is a significant workplace hazard. If HSI is between 70 and 100, heat stress is high and workers are at risk for heat-related disorders. If HSI is greater than 100, there is significant heat storage and the exposure is time-limited.

A number of variations to HSI as well as alternatives have been proposed. The International Organization for Standardization has published the most recent and comprehensive rational method for heat balance analysis. It is called the Required Sweat Rate (SR_{req}) Analysis and the steps are described in Figure 12–7. (This method is under review by the ISO, and improvements have been proposed but not yet voted on.)

The principle of the ISO method is to determine (1) the amount of evaporative cooling that is required for thermal equilibrium (E_{req}), (2) whether the required cooling can be achieved by sweating and evaporation, and (3) what time limits may apply if sweating or evaporation is insufficient. The limits are based on inadequate cooling and potential dehydration. (The standard was developed with cotton clothing in mind, but experimentally derived values of insulation (I_{cl}) and permeability (F_{pcl}) for other clothing ensembles are becoming available for use, such as the method suggested by Barker, Kini and Bernard [1999].)

If the heat-balance analysis indicates that thermal equilibrium can be achieved, then heat stress does not play a limiting role in the work. If the time limits are less than six hours, then serious consideration must be given to heat-stress controls.

The accuracy of heat-balance analysis is limited because certain variables are not easily measured, but fair assumptions can be made. The important advantage of heat-balance analysis is the ability to compare the relative advantages of proposed changes in the environment, work demands, and clothing requirements.

EVALUATION OF PHYSIOLOGICAL STRAIN

As mentioned earlier, physiological strain due to heat-stress exposures is seen as elevations in core temperature, heart rate, and sweating. They are therefore candidates as evaluation tools for heat stress exposures. Physiological evaluation is a valid approach because it uses direct assessment of the effects of heat stress (dose) rather than an index of exposure, which is then related to dose through empirical evidence and models. The recently adopted TLV for Heat Stress and Strain® reflects the value placed on physiological monitoring. If no excessive physiological strain is demonstrated in the working population at a workplace, then heat stress is controlled by the work practices in place.

Physiological evaluation as an alternative or confirming evaluation of heat stress may be worthwhile when protective clothing is required. It might also be used to demonstrate

compliance with the spirit of the NIOSH and ACGIH thresholds when some work occurs just above the thresholds.

In selecting workers to sample for the physiological evaluations, the choice should be random and sufficient to ensure statistical reliability.

Core temperature is a physiological construct used to describe internal body temperature. There are several laboratory methods used to assess core temperature that are not acceptable in a workplace. Acceptable surrogate methods are available. The surrogate with the longest history is oral temperature. To take an accurate oral temperature, the individual must not eat or drink for 15 minutes prior to the sample and the mouth must remain closed. Core temperature is approximately equal to oral temperature plus 0.5 C or 1 F.

Other alternatives are available. One is a commercial personal monitor with data-logging capabilities that monitors ear canal temperature with a thermistor held in place by a disposable ear plug. Another commercial device estimates core temperature from a surface-mounted sensor placed on the chest (and is part of a heart-rate monitoring device described later in this section). Finally, there are swallowable "pills" that can transmit a value for temperature to a receiver outside of the body.

As a criterion for core temperature, 38 C (100.4 F) is the limit if the temperature is sustained over the course of the work day. If the work is intermittent, then transient increases to 39 C (102.2 F) should be acceptable as long as there is sufficient recovery to allow core temperature to return toward 37 to 37.5 C (98.6 to 99.5 F). That is, the time-weighted average should not exceed 38 C (100.4 F). As a matter of practice, core temperature should not exceed 39 C (102.2 F) for industrial exposures to heat stress.

Heart rate is another indicator of heat strain. Four methods proposed for assessing heart rate are in use. Three methods mentioned previously are recovery heart rate, peak heart rate and average heart rates over an 8-h duration. Another method evaluates a set of averaged heart rates over a typical exposure period.

Recovery heart rate was mentioned previously as a tool for recognition. It has also been used to evaluate workplaces. To demonstrate effective control of heat stress, the recovery heart rate at one minute (HRR_1) should be less than 110 bpm. Alternatively, the heart rate at three minutes (HRR_3) should be less than 90 bpm or the value of $HRR_1 - HRR_3$ should be at least 10 bpm.

If the daily average heart rate exceeds 110 bpm, then heat stress and/or very strenuous work may be the cause. This limiting average has been recommended by the WHO experts and confirmed in laboratory and field studies.

Setting a threshold for heart rate is a third approach. A recording of heart rate during a heat stress exposure is shown in Figure 12–9. As a rule of thumb, peak heart rates should not exceed 90 percent of a person's maximal heart rate (HR_{max}). Sometimes this value is known from a stress test and other times it must be estimated from age (e.g., $HR_{max} = 195 - 0.67$[age–25 years]). Brief periods (less than one minute) above this threshold are not significant, but more than one minute may be excessive. The ACGIH has recommended limiting sustained heart rates of several minutes to 180 – Age.

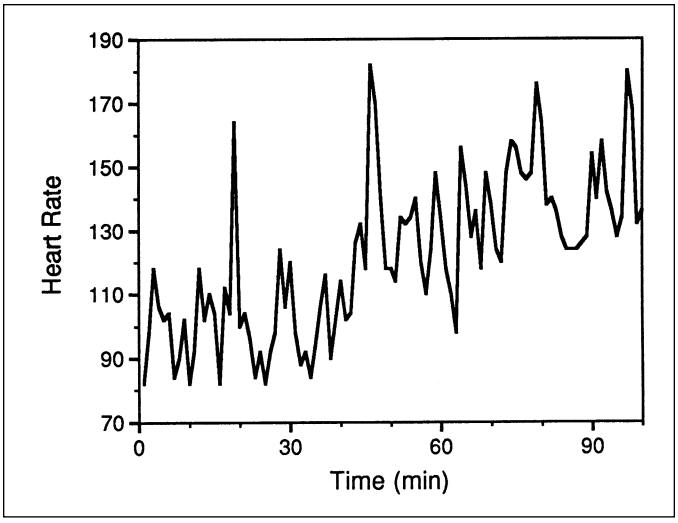

Figure 12–9. Example of a heart rate response to a heat-stress exposure.

When looking over a history of heart rate for the day, an obvious trend toward higher heart rates also indicates heat stress above the thresholds because the body is having trouble maintaining thermal equilibrium. The momentary peaks in Figure 12–9 are not significant, but the trend in the second half is a classic representation of the response to moderately high heat stress and eventually excessive cardiovascular strain.

There is also a personal monitor commercially available that sets multiple thresholds for heart rate based on averages in seven different time windows. The purpose of this approach is to examine the peak demands as well as the overall trends for a broader evaluation. This device is the one mentioned previously that also has a surface sensor surrogate for core temperature. If the sample of workers stay below the thresholds in this device then heat stress is not significant.

Sweat rate and volume are theoretically measures of physiological strain, but less practical than core temperature and heart rate. Sweat volume over a given period of time is equal to an initial body weight plus the weight of food and drink consumed minus the weight of anything excreted minus a final body weight. The overall weight change in kilograms is equal to the sweat volume in liters. If there is more than a five-liter sweat volume, heat stress is sufficient to cause dehydration and therefore must be controlled. Over a two- to four-hour interval, the sweat rate should be less than one liter per hour.

Control of Heat Stress

Control of heat stress and heat strain centers around the causes of heat stress and the resulting physiological strain. It takes the form of general controls that are applicable to all heat-related jobs, and specific controls that must be evaluated and selected based on the constraints of the working conditions. The controls are divided into general and specific controls.

GENERAL CONTROLS

General controls are those actions that are universally applicable to heat stress work. The general controls are training, heat-stress hygiene practices, medical surveillance, and a heat-alert program. Anytime a group of workers may be exposed to heat stress that is above the RAL (or equivalently the TLV for Unacclimatized Workers), the general controls should be implemented.

Training is an essential feature of managing heat stress. It is for those employees working on heat-related jobs and their supervisors. The information gained from the training enables them to recognize heat stress and to control the risks associated with it. Training is divided into two types—preplacement and periodic.

Preplacement training. Preplacement training is directed to an employee who is reporting to a heat-related job for the first time. The preplacement training can be given during other job training including safety or skill training. It is not necessary to repeat preplacement training for an employee who has had it once. The formal content of the preplacement training is the same as that for annual or periodic training (see the next paragraph). A complement to the preplacement training is any counseling medical personnel may give an individual employee relating to that employee's physical condition.

Periodic training. Annual heat-stress training should be given to employees working on heat-related jobs to refresh their knowledge of heat stress and controls. The following topics should be covered during training:

- ➢ Description of Heat Stress
  - ➢ Environment, work demands, and clothing
  - ➢ Physiological responses including acclimation
- ➢ Recognition of and First Aid for Heat-Related Disorders
  - ➢ Description of heat-related disorders including symptoms and causes
  - ➢ Description of first aid measures for each disorder
- ➢ Heat Stress Hygiene Practices (see following for details)
  - ➢ Description of heat stress hygiene practices
  - ➢ Emphasis on individual responsibility
- ➢ Overview of Heat Stress Policy and Guidelines
  - ➢ Company Policy
  - ➢ Management responsibilities
  - ➢ Employee responsibilities

The format of the training can be similar to other health and safety training. Using commercially available videotape and written materials is effective and efficient. However, it is important to point out those issues that may be particular to the work site.

Heat stress hygiene practices. Heat-stress hygiene practices are the actions taken by an individual to reduce the risks of a heat disorder. The individual is responsible for practicing good heat stress hygiene. Site management informs the workers of good practices and helps the workers practice them. Some practices are listed.

Fluid replacement—A great deal of water is lost from the body as sweat for evaporative cooling. Losses may be up to six liters or quarts of water in one day, equivalent to about 13 pounds. This water should be replaced by drinking cool water or flavored drinks (e.g., dilute iced tea, artificially sweetened lemonade, or commercial fluid-replacement drinks). Because thirst is not a sufficient driver for water replacement, workers should drink small quantities as frequently as possible. This helps instill drinking as a habit and the volumes do not cause discomfort. If work is to be performed in a drinking-restricted area, drinking about one pint per hour of work before the work begins will help meet the demands for water during the work.

Unacclimated workers in jobs with exposures near the TLV® may benefit from drinking beverages containing about 0.1 percent salt. Workers on physician-advised salt-restriction should consult their physician. (Note: Salt tablets should never be taken.)

Self-determination—One aspect of self-determination is limiting an exposure to heat stress. It is a responsibility of the worker and supervisor(s). In self-determination, the person terminates an exposure to heat stress at the first symptom of a heat-related disorder or extreme discomfort. Serious injury can occur if the onset of symptoms is ignored.

Another aspect of self-determination is reducing the effects of heat stress by lowering peak work demands and making the work demands lighter. For instance, when a fixed amount of work is assigned to a portion of the shift, peak demands can be reduced by leveling out the work effort over the allocated time or taking more frequent breaks. For those working in crews, the pace should be set for the least heat-tolerant worker.

Diet—A well-balanced diet is important to maintain the good health needed to work under heat stress. Large meals should not be eaten during work breaks because they increase circulatory load and metabolic rate.

Diets designed to lose weight should be directed by a physician who understands that the patient is working under conditions of potential heat stress. Weight control for overweight workers is recommended because obesity increases the risk of heat-related disorders.

Salt intake as part of a normal diet is usually sufficient to meet the salt demands during heat-stress work. Added salt may be desirable when repeated heat stress exposures are first experienced (i.e., during acclimation). If salt is restricted by a physician's order, the physician should be consulted.

Lifestyle—A healthy lifestyle is important to lowering the risk of a heat-related disorder. A worker should have adequate sleep and a good diet. Exercise helps. A healthy lifestyle also means no abuse of alcohol or drugs, which have been implicated in heat strokes. In addition, exposures to heat stress immediately before work may increase the risk of a heat disorder at work.

Health Status—All workers should recognize that chronic illnesses, such as heart, lung, kidney, or liver disease, indicate a potential for lower heat tolerance and therefore an increased risk of experiencing a heat-related disorder during heat-stress exposures. As a matter of principle, workers suffering from any chronic disorder should inform the physician of occupational exposures to heat stress and seek advice about the potential effects of the disorder or drugs used to treat it.

If a worker is experiencing the symptoms of any acute illness and still reports to work, that worker should inform the immediate supervisor.

Acclimation—Acclimation is the adaptation of the body to prolonged daily heat stress exposures. The ability to work increases and the risk of heat disorders decreases with acclimation. Acclimation is lost when there are no heat exposures. The loss is accelerated when an illness occurs. The process should be recognized and expectations adjusted. Workers will be able to work better after several days of heat exposures and they should expect less of themselves in the early days.

Table 12–E provides a framework for how acclimation can be induced and re-induced after an absence from heat exposures. Recommendations for new worker acclimation usually start at lower levels to further account for the lack of familiarity with the job and therefore greater risk of accidents. This is reflected in the five-day schedule that begins at 20 percent of daily exposure. For experienced workers, OSHA recommendations prescribe three days of increasing exposures followed by full exposures. Recognizing that full acclimation is normally lost over three weeks, the reacclimation schedule in Table 12–E is recommended by the author.

Table 12–E. ***Basic Acclimation Schedule and a Schedule for Reacclimation after Periods Away from Heat Stress Exposures Due to Routine Absence or Illness***

Basic Acclimation Schedule

Day	*Activity (% of full work assignment)*	
	Experienced	*New*
Day 1	50	20
Day 2	60	40
Day 3	80	60
Day 4	100	80
Day 5		100

Reacclimation Schedule

Days Away from Heat-Related Schedule		*Exposure Sequence (% of full work assignment)*			
Routine Absence	*Illness*	*Day 1*	*Day 2*	*Day 3*	*Day 4*
<4	—	100			
4–5	1–3	R/E*	100		
6–12	4–5	80	100		
12–20	6–8	60	80	100	
>20	>8	50	60	80	100

* Reduce expectations, some diminished capacity

Medical surveillance—This encompasses the evaluation of individual risk for adverse effects to heat-stress exposures, provides treatment for heat-related disorders, and helps assess the information collected from heat-related disorder incidents. Medical surveillance should be under the direction of a licensed physician.

Evaluation of risk—The medical surveillance activity includes identifying those workers who may be at extraordinary risk for heat-related disorders. Preplacement and routine physicals under the direction of the physician are used to identify these people. The physician should consult the NIOSH Criteria Document for more information, but ultimately the physician must set the criteria.

Before an employee is placed on a heat-related job, the employee should receive a preplacement physical examination that covers the following items:

- ➢ Comprehensive work and medical history with an emphasis on past intolerance to heat stress and relevant information on the cardiovascular, respiratory, and nervous systems; skin; liver; and kidneys
- ➢ Comprehensive physical examination that gives special attention to the cardiovascular, respiratory, and nervous systems; skin; liver; kidneys; and obesity
- ➢ Assessment of the use of prescription and over-the-counter drugs as well as the abuse of alcohol or other drugs that may increase the risk of heat intolerance
- ➢ Assessment of ability to wear and use personal protection that may be required
- ➢ Assessment of other factors that may affect heat tolerance as deemed important by the physician-in-charge. The physician should provide a written opinion of the results, which is placed in the employee's medical file. A copy should be provided to the employee. The written opinion should contain the following:
  - ➢ results of the examination and tests
  - ➢ physician's opinion on potential risk to the employee
  - ➢ physician's opinion on the employee's capability to work on heat-related jobs
  - ➢ any recommended limitations or restrictions
  - ➢ a statement that the employee has been informed of the results

Because an employee's health status can change over time, periodic re-evaluations are appropriate. These periodic physicals should be scheduled approximately yearly. There may be times when the physician or management believes that the ability of an individual to tolerate heat stress has diminished. In this case, the physician may perform a timely physical outside the schedule for a periodic physical examination.

Response to heat-related disorders—The organization's medical department is responsible for providing emergency response to reported heat-related disorders directly through medical department facilities, by medical department

personnel at the job site, or by providing first aid training to selected department foremen or safety personnel.

In addition to providing for emergency response, the physician or designee (e.g., safety department personnel) should periodically review heat-stress incidents to update the program.

Heat-alert programs are a collection of activities taken in anticipation of heat-stress conditions or an unusually high level of heat stress. These conditions may be the approaching of summer, of a maintenance outage, of special operating conditions, or of a heat wave. The first step in a heat-alert program is to appoint a committee whose members are responsible for the annual review of heat stress management activities and to make adjustments as necessary. This committee should be comprised of management representatives from such departments as operations, maintenance, engineering, medical, industrial hygiene, safety, and human resources as well as representatives of labor from different departments that may be affected. It should meet well before the anticipated presence of heat stress in the workplace. At a minimum, the committee should complete the following activities:

- ➢ Review training materials and set training schedule for the current year
- ➢ Oversee the preparation of the facility for heat stress conditions (e.g., reverse winterization) and check the operability of heat stress controls (e.g., fans, air conditioners, drinking stations, personal protection)
- ➢ Oversee the preparations for changes in staffing and work practices if appropriate
- ➢ Review policies and procedures regarding heat-related disorders
- ➢ Prepare for extraordinary heat stress conditions by
  1. setting criteria for a Heat-Alert State (such as a sudden increase in ambient temperatures from a heat wave) and how it will be announced
  2. preparing special administrative controls (see below) such as rescheduling work, increasing the number of workers, further restricting overtime, personal monitoring for excessive heat strain, etc.
  3. closely monitoring workers for heat-related disorders

SPECIFIC CONTROLS

The two major factors in heat stress are work demands and environmental conditions (i.e., air temperature, humidity, air movement, and hot surfaces). Clothing requirements are a third factor when multiple layers, nonwoven clothing, or vapor-barrier fabrics are worn. For specific jobs, the control of heat stress and the resulting physiological strain on workers is accomplished through engineering controls, administrative controls and personal protection.

Table 12–F is a checklist of controls suggested by NIOSH in the revised criteria document. The table is one way to begin to understand what might be done to manage the level of heat stress. While each job must be examined in light of the work to be accomplished and the constraints of the workplace, the following discussion highlights the principles of the control measures and can be used to focus discussion of controls.

To select controls for specific jobs, the first step is to discuss the job among production, engineering, and health and safety functions using the following discussion of control measures. A "long list" of ideas that emphasizes engineering controls, followed by administrative controls, and finally personal protection should be generated. Imagination is essential during the development of candidate controls for the long list, and no candidate control should be rejected out-of-hand. Controls should then be judged on their merits as they relate to being effective and technically and economically reasonable. The result is a "short list" of controls that can be prioritized and implemented over a reasonable timeframe. It is reasonable to have short-term solutions while long-term solutions are planned and executed.

Engineering controls. These are the kind of controls that reduce or contain the hazard. For heat stress, engineering controls are directed toward reducing physical work demands, reducing external heat gain from the air and hot surfaces, and enhancing external heat loss by increasing sweat evaporation and decreasing air temperature.

Reduce physical work demand. The metabolic cost of doing work is the greatest contributor to heat gain by a worker. Reducing the physical work demand can greatly reduce the level of heat stress.

Ways that the physical work demand can be reduced usually include powered tools or new processes to reduce manual effort.

Reduce air temperature. When air temperature is above 40 C (104 F), workers gain a significant amount of heat from the air. If the air temperature is below 32 C (90 F), there is a significant loss of body heat. Lowering air temperature serves to either reduce heat gain or enhance the loss of heat. It is a significant factor in the control of heat stress.

Air temperature can be reduced by dilution ventilation and active cooling. Dilution ventilation brings in a supply of cooler air from another area and reduces the temperature in the work area by diluting the hot air with cooler air. This can be accomplished using general area ventilation or local (spot) ventilation. Active cooling means that mechanical refrigeration, evaporative cooling, or a water chiller is employed to reduce the temperature of supplied air for dilution ventilation. Cool rooms are an example of providing a local area of cooling near work areas. By spending some time of the work cycle in the cooler area, the effective exposure to heat stress is reduced.

Reduce air humidity. The rate of evaporative cooling of sweat is affected by the air humidity. Many times the rate of cooling is sufficiently restricted that excessive heat strain occurs. The rate of evaporative cooling can be enhanced by

Table 12–F. *Overview of Specific Controls for Heat Stress Provided by NIOSH in the Criteria Document for Heat Stress*

Item	*Actions for Consideration*
Controls	
M, Body heat production of task	Reduce physical demands of the work, powered assistance for heavy tasks.
R, Radiative load	Interpose line-of-sight barrier, furnace wall insulation, metallic reflecting screen, heat reflective clothing, cover exposed parts of body.
C, Convective load	If air temperature is above 35 C (95 F), reduce air temperature, reduce air speed across skin, wear clothing. If air temperature is below 35 C (95 F), increase air speed across skin and reduce clothing.
E_{max}, Maximum evaporative cooling by sweating	Increase by: decreasing humidity, increasing air speed Decrease clothing
Work practices	Shorten duration of each exposure; more frequent short exposures better than fewer long exposures. Schedule very hot jobs in cooler part of day when possible.
Exposure limit	Self-limiting, based on formal indoctrination of workers and supervisors on signs and symptoms of overstrain.
Recovery	Air-conditioned space nearby.
Personal protection R, C, and E_{max}	Cooled air, cooled fluid, or ice cooled conditioned clothing. Reflective clothing or aprons
Other considerations	Determine by medical evaluation, primarily of cardiovascular status Careful break-in of unacclimatized workers Water intake at frequent intervals to prevent hypohydration Fatigue or mild illness not related to the job may temporarily contraindicate exposure (e.g., low-grade infection, diarrhea, sleepless night, alcohol ingestion)
Heat wave	Introduce heat alert program

(Reprinted from *NIOSH Criteria for a Recommended Standard . . . Occupational Exposure to Hot Environments—Revised Criteria 1986*. Washington, DC: U.S. Government Printing Office, 1986.)

lowering the water content of the air. Water is best removed from air by cooling the air by water chillers or mechanical refrigeration. Thus heat stress is reduced by both removing water vapor and lowering air temperature. Again, the use of cool rooms reduces heat stress by lower air temperatures and by lower humidity (and the increased rate of evaporative cooling).

Change clothing. Clothing is an important contributor to heat stress if it is not a light-weight cotton work uniform. Frequently, when clothing is chosen for good barrier properties against contaminants, not enough thought is given to the effects on heat stress. For instance, when the WBGT is 32 C (90 F) (T_{db} = 38 C or 100 F) at a moderate rate of work (about 260 W), a person in work clothes can work for about two hours while a person in vapor-barrier clothing can work about 30 min. Changing the vapor-barrier to a water-barrier (vapor-transmitting) clothing can increase the tolerance time to 70 min.

Reduce radiant heat. When the globe temperature is greater than 43 C (109 F), radiant heat is a significant source of heat stress. Radiant heat can come from well-defined or diffuse sources with high surface temperatures.

If a source of radiant heat is well-defined and localized, it can be effectively controlled by shielding. Diffuse sources of radiant heat are more difficult to control. For diffuse sources, control can come from shielding, but two other means are also available. One is insulating surfaces to reduce surface temperature and the other is to decrease emissivity of the surface. Increasing the insulation may also reduce air temperature and decrease energy costs.

Increase air movement. The advantage of increasing air movement is to enhance evaporative cooling and convective cooling if the air temperature is less than 35 C (95 F). Between 35 and 40 C (95 and 104 F), heat gain by convection may increase with increases in air movement, but it will be more than off-set by increases in evaporative cooling. Above 40 C (104 F), increases in air movement actually increase the overall heat stress. The greatest reduction in heat stress occurs when air motion is increased from less than one meter per second (m/s) to 2 m/s. There is no further improvement in evaporative cooling for air speeds greater than 3 m/s. When clothing is fairly heavy, higher air speeds can better penetrate the clothing and move the air near the skin (clothing ventilation is increased).

The chief mechanism for increasing air movement around a worker is to use a fan in the workspace. Another means of increasing air motion is local ventilation. Increasing air movement, however, frequently increases the level of airborne particles.

Administrative controls are controls that change the way work is performed in order to limit exposures or risks. For heat stress, administrative controls are directed toward limiting exposures so that increases in heart rate and core temperature do not exceed accepted limits.

Acclimation. Acclimation is the process that allows a worker to become accustomed to the heat stress; the worker is better able to work in the heat. Acclimation is a powerful adaptation that comes naturally to more than 95 percent of the workforce. Acclimation is usually set according to a schedule of increasing exposures. A schedule for acclimation and reacclimation is provided in Table 12–E.

An alternate method is to control the exposures to a level equivalent to the *Alert Limit*. This alternative approach requires more attention to the work methods and environment and is not routinely done.

Pacing of the work. Because work metabolism is an important contributor to heat stress, methods to reduce the rate of metabolism can go a long way toward reducing heat stress. The rate is reduced when the same amount of work is performed over a longer period of time. Any idle time inherent in the work should be spent in cooler areas to realize the full benefit.

For instance, many jobs have a fixed amount of work to be accomplished, and the workers are given an allotted time. The tendency in cool conditions is to work very fast and have the remaining time idle. The same pace in hot environments can cause excessive heat strain. So when the environment is hot, the work should be leveled out to reduce the rate of metabolism and the potential for excessive heat stress.

Sharing the work. Another way to reduce metabolism is to share or distribute the work among other workers. This may require some work to be delayed to another time. In scheduling the work, thought should be given on how to use the staff most efficiently and effectively. For instance, it may be possible that a worker can move between two crews during the same work period and still have an effect on reducing heat stress. Further, workers might straddle a work shift so that they work the second half of the day shift and the first half of the afternoon shift, when heat stress is most likely to be a problem.

Scheduling of work. An administrative control to reduce the contribution of environmental heat to heat stress is to schedule nonessential work at cooler times of day or during cooler periods.

Work times, self-determination, and personal monitoring. Preplanned work times, self-determination, and personal monitoring are ways to control a heat-stress exposure that is known to be high. Predetermined work times are assigned to a worker or crew before a job begins. They may extend the work time with the knowledge that heat stress will eventually affect their ability to work and there is a risk of heat-related disorder. The extension should be under the controls of self-determination aided by personal monitoring.

The purpose of self-determination with personal monitoring is to allow more heat-tolerant workers to work longer than less-tolerant ones by letting the worker stop an exposure. These kinds of administrative controls apply better to self-paced and nonroutine work, and may be more difficult to manage during externally paced work. Self-determination is best instituted as a periodic query to the individual workers about their subjective judgment of heat strain and their ability to continue. Because subjective decisions are unreliable, objective data on heat strain should be obtained from personal monitoring of body temperature and/or heart rate. In 2000, there are at least three electronic personal monitors designed for industrial use that are commercially available. One device examines body temperature through a measure of ear canal temperature, and the second examines both heart rate and body temperature (through a surface sensor). There is a third type that measures deep body temperature through an ingested "pill." The first two types are shown in Figure 12–10. There are also heart-rate monitors, and oral temperature devices suitable for occupational applications.

Personal protection. Personal protection is a control that provides protection for an individual worker. For heat stress, personal protection is primarily some form of personal cooling, but can include reflective clothing for high radiant heat conditions. Personal cooling systems, if chosen to match the job situation, can significantly increase the safe exposure time. When personal protection is used, conventional evaluation methods do not apply and work practices must be developed for the successful use of personal protection for heat stress.

Circulating air systems. Circulating air as a personal cooling method is achieved by circulating air under the clothing and around the torso. It requires the delivery of air to the individual either (1) through a high-pressure air line and a pressure reducer or (2) through a portable (self-contained) blower. Circulating air under the clothing effectively increases the amount of convective and evaporative cooling of the body. (Note: The circulating air must be breathing-grade air.)

While air-line systems can be used continuously for work that is relatively stationary, the technique can be used profitably by workers as temporary relief during pauses in the work. If there is a sufficient supply of compressed air, vortex devices can be used to significantly reduce the air temperature (on the order of a 10 C [18 F] reduction) going into the clothing.

Portable blower systems are just receiving attention. Because they use air in the work locale, they may not provide as much cooling capacity as air-line systems delivering the same volume flow rate.

Circulating water systems. A second type of personal cooling is a system that circulates cool water through tubes and channels around the body. There are a variety of systems available. First, systems range from those that can cover virtually the whole body to those that cover only portions of the back and chest. There are also portable versions as well

Figure 12–10. Photographs of two commercially available personal monitors developed for heat-stress exposures. (Courtesy of Metrosonics, Inc, and Quest Technologies.)

as versions with a heat sink that is connected to the person through a tether. The degree of cooling that can be achieved depends on surface area covered, rate of water circulation, and the capacity of the heat sink.

The selection of circulating water systems should be done in consultation with the vendors and someone very familiar with personal cooling in order to obtain a good match.

Ice garments. Several frozen-water (ice) garments, frequently called ice vests, are commercially available. They control heat strain by removing body heat via conduction from the skin to packets of ice. The typical vest weighs about 5 kg. The vests provide good mobility with some bulk around the torso. The ability to cool and service time depend on the rate of work, the amount of ice, and design of the garment. For a given amount of work, the time is limited by the ice. Service times up to two hours are reasonable from some models of ice vests.

Nonwater phase-change materials are also available in cooling garments. Appreciating that the service time depends on the total heat-absorbing capacity of the heat sink, a relative comparison can be made to ice vests by comparing the total heat of fusion of a nonwater system to 320 kcal in 4 kg of ice.

Reflective clothing. While personal cooling is designed to take up body heat, reflective clothing is designed to reduce the amount of heat reaching the individual. Reflective clothing is best suited for sources of high radiant heat. There is a trade-off with reflective clothing in that it reduces sweat evaporation. That means that the level of heat stress may actually increase if the reflective clothing is not selected to best match the source of radiant heat and the job.

Hot Surfaces, Hot Air, and Respirators

Work in hot environments usually means that there are hot surfaces with the accompanying potential to cause a burn. The potential for a burn (or to elicit pain at a somewhat lower level of heat transfer) depends on the thermal conductivity of the solid, the temperature of the solid, and the contact time with skin. Table 12–G provides approximate surface temperatures for common surfaces that may elicit pain or a burn with brief (1 s) contact time and burns with longer contact times. For prolonged contact, surface temperature is the dominant characteristic. To avoid tissue injury, the surface temperature should be less than 48 C (118 F) for up to 10 minutes of contact time and 43 C (109 F) for prolonged contact. There will be reports of extreme discomfort with surface temperatures greater than 38 C (100 F).

Sometimes there is a concern about the temperature of the air that is being breathed. If the wet bulb temperature of the air is less than 45 C (113 F), breathing the air is not likely to cause extreme discomfort or ill effects. There are laboratory observations of sustained breathing at wet bulb temperatures of 50 C (122 F) without complaint. Above these temperatures, the probability of individual discomfort will increase.

There is a frequently expressed concern about the effects of tight-fitting, full-face respirator facepieces on heat stress—usually that negative-pressure respirators increase the level of heat stress and that air-supplied respirators may give a false sense of cooling. There are small changes in the level of physiological response, but not enough that the heat-stress guidelines for evaluation described previously should be adjusted to account for respirator use. There is also no doubt that subjectively measured discomfort increases while wearing a respirator facepiece in hot environments, and this may affect performance.

COLD STRESS

Cold stress is fundamentally a different kind of problem than heat stress. While adaptive mechanisms (i.e., sweating and acclimation) are crucial during heat-stress exposures, the physiological adaptations to cold stress have less dramatic effects. The first physiological response to cold stress is to conserve body heat by reducing blood circulation through the skin. This effectively makes the skin an insulating layer. A second physiological response is shivering, which increases the rate of metabolism. Shivering is a good sign that the cold stress is significant and that hypothermia may be present. However, it is relatively weak as a protective mechanism. Behavior is the primary human response to preventing excessive exposure to cold stress. Behaviors include increasing clothing insulation, increasing activity, and seeking warm locations.

Insulation is a critical characteristic of clothing worn during cold-stress exposures. Clothing materials used for their insulating characteristics include cotton, wool, silk, nylon, down, and polyester insulation. Generally, the insulating value of clothing ensembles comes from layering clothes rather than having one garment. The further advantage of layers is that the person can add or remove layers to adjust for differing insulation needs during the work period.

The insulating value of clothing is greatly diminished by moisture. Sources of water are the work environment and sweat. Water-vapor permeability is also important. If sweat is allowed to evaporate through the clothing, it will not accumulate in the clothing. Once clothing becomes wet, it is important to replace it immediately.

Like layering, clothing ventilation is a valuable means to adjust the heat-transfer properties of the ensemble. During low levels of work, insulation demands are high; as the work rate increases, insulation must decrease to maintain thermal equilibrium. Besides removing layers, the effective insulation of the ensemble can be reduced by increasing the air movement under the clothing by increasing the clothing ventilation.

Table 12–G. *Limits on Surface Temperature (in degrees Centigrade) to Avoid Pain and Burns with Different Contact Periods Against Skin*

Material	*Pain (1 s)*	*Burn (1 s)*	*Burn (4 s)*	*Burn (10 min)*	*Burn (prolonged)*
Metals	45	65	60		
Glass	55	85	75		
Wood	75	115–140 (depends on dryness of wood)	95–120		
Any material				48	43

(Adapted from Eastman Kodak, 1983; Siekmann, 1990)

Hazards associated with cold stress are manifested in two distinct fashions: systemic (hypothermia) and local (localized tissue damage). There is also a concern for manual dexterity. The disorders related to cold stress exposures are described in Table 12–H.

As hypothermia progresses, depression of the central nervous system becomes more severe. This accounts for the progression of signs and symptoms from a sluggishness through slurred speech and unsafe behaviors to disorientation and unconsciousness. The ability to sustain metabolic rate and reduced skin blood flow is diminished by fatigue. Thus fatigue increases the risk of severe hypothermia through decreasing metabolic heat and increased heat loss from the skin. Because blood flow through the skin is reduced to conserve heat, the skin and underlying tissues are more susceptible to local cold injury.

Model of Thermal Balance

Systemic cold stress can be examined in terms of heat exchange.

$$S = M + (R + C) + K + E \qquad (13)$$

M is metabolic rate and represents a source of internal heat gain. $(R + C)$ is the combination of heat loss due to cooler air and surroundings. K is conduction to a solid surface in contact with the body. E is evaporative cooling by sweat evaporation; it has a negative value because the flow of heat is away from the body. Thermal equilibrium is established when $S = 0$.

M can be increased as a behavioral response to cold stress, and significant contributions to thermal balance are reductions in $(R + C)$ and K with behavioral adaptations like clothing and avoidance of cold environments. For a given level of clothing, the greater the work demands (greater metabolic rate) the greater the level of cold stress that can be tolerated.

The goal of systemic cold stress control is to avoid hypothermia by limiting the reduction in core temperature to 36 C (96.8 F) for prolonged exposures and to 35 C (95 F) for occasional exposures of short duration.

Table 12–H. *Cold-Related Disorders Including the Symptoms, Signs, Causes, and Steps for First Aid*

Disorder	*Symptoms*	*Signs*	*Causes*	*First Aid*
Hypothermia	Chills Pain in extremities Fatigue or drowsiness	Euphoria Slow, weak pulse Slurred speech Collapse Shivering Unconsciousness Body temperature <95 F (35 C)	Excessive exposure Exhaustion or dehydration Subnormal tolerance (genetic or acquired) Drug/alcohol abuse	Move to warm area and remove wet clothing Modest external warming (external heat packs, blankets, etc.) Drink warm, sweet fluids if conscious Transport to hospital
Frostbite	Burning sensation at first Coldness, numbness, tingling	Skin color white or grayish yellow to reddish violet to black Blisters Response to touch depends on depth of freezing	Exposure to cold Vascular disease	Move to warm area and remove wet clothing External warming (e.g., warm water Drink warm, sweet fluids if conscious Treat as a burn, do not rub affected area Transport to hospital
Frostnip	Possible itching or pain	Skin turns white	Exposure to cold (above freezing)	Similar to frostbite
Trench Foot	Severe pain Tingling, itching	Edema Blisters Response to touch depends on depth of freezing	Exposure to cold (above freezing) and dampness	Similar to frostbite
Chilblain	Recurrent, localized itching Painful inflammation	Swelling Severe spasms	Inadequate clothing Exposure to cold and dampness Vascular disease	Remove to warm area Consult physician
Raynaud's disorder	Fingers tingle Intermittent blanching and reddening	Fingers blanch with cold exposure	Exposure to cold and vibration Vascular disease	Remove to warm area Consult physician

Note: Hypothermia is related to systemic cold stress, and the other disorders are related to local tissue cooling.

Measurement of Cold Stress

Two climatic factors in the environment influence the rate of heat exchange between a person and the environment. These factors are air temperature and air speed. As the difference between skin and ambient temperatures increases and/or the air speed increases, the rate of heat loss from exposed skin increases. The rate of heat loss is approximated by Equation 14.

$$H = 1.16(10\,V_{air}^{\ 0.5} + 10.45 - V_{air})(33 - T_{db})(\mathrm{W/m^2}) \quad (14)$$

The *Equivalent Chill Temperature (ECT)* (also known as the *Wind Chill Index*) was developed by the U.S. Army to account for both air temperature and air speed based on empirical observations of the time for water to freeze. It has been updated by the National Weather Service. The recently published *Wind Chill Index* chart is shown in Table 12–I as it relates air temperature and speed.

Recognition

Subjective responses of workers are a good tool for recognition of cold stress in the workplace. If the workplace is generally described as cold, then cold stress may be present. Worker behaviors to cold stress exposures will generally be those that are seeking warm locations, adding layers of clothing or increasing the work rate. Other behaviors are loss of manual dexterity, shivering, accidents, and unsafe behaviors.

Using the first aid logs and other records, is there a pattern of signs and symptoms that might be attributed to hypothermia? A physiological marker is reduced core temperature, below 36 C (96.8 F).

If there is a noticeable drop in manual dexterity reported by workers or supervision, local cold stress is possible. In addition, if there is a pattern of cold-related disorders reported in the first aid logs, injury and illness logs, and workers compensation records, the work conditions should be evaluated.

Evaluation

WORKPLACE MONITORING

When temperatures fall below 16 C (61 F), workplace monitoring should be instituted. Below –1 C (30 F), the dry bulb temperature and air speed should be measured and recorded at least every four hours. When air speed is greater than 2 m/s (5 miles per hour, mph), the ECT should be determined from Table 12–I. When the ECT falls below –7 C (19 F), it should also be recorded.

Table 12–I. *National Weather Service Wind Chill Index in Degrees F for Different Combinations of Air Temperature and Air Speed (also known as the Equivalent Chill Temperature)*

Air Speed mph	Temperature [F]																		Air Speed m/s
Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	Calm
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63	2
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72	4
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77	7
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81	9
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84	11
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87	13
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89	16
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91	18
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93	20
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95	22
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97	25
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98	27
Time to Frostbite							30 min		10 min					5 min					Time to Frostbite
Calm	4	2	-1	-4	-7	-9	-12	-15	-18	-21	-23	-26	-29	-32	-34	-37	-40	-43	Calm
	Temperature [C]																		

Note: Cross-reference to metric units for air speed and temperature are provided.

SYSTEMIC COLD STRESS

Hypothermia can occur with air temperatures up to 10 C (50 F). The ACGIH recommends that the employer become involved with protective measures when air temperature is less than 5 C (41 F). Equation 15 can be used to approximate the amount of clothing insulation (I_{clo} in clo units, where 1 clo = 0.155 m^2 C / W) required for a specific task in a given air temperature (T_{db} in C) and metabolic rate (M in watts). Figure 12–11 illustrates the relationship among temperature, work rate, and clothing to maintain thermal equilibrium based on Equation 15.

$$I_{clo} = 11.5\,(33 - T_{db}) / M \qquad (15)$$

Remember that the clothing must be kept dry and that I_{clo} will change with different tasks and environments.

As the environmental conditions become very cold, rewarming periods should be provided. Specific rewarming schedules are provided in the TLV for Cold Stress® (see Appendix B, ACGIH Threshold Limit Values and Biological Exposure Indices, Cold Stress, Table 3). The maximum exposure time depends on air temperature and ambient air movement and is followed by a 10-minute warmup break. Reductions in the working time are recommended if the work rate is low to moderate, because internal heat generation will be lower. There is a point at which nonemergency work should not be performed.

LOCAL COLD STRESS

Skin cannot freeze until the air temperature is less than –1 C (30 F) and there is little risk of local cold injury associated with ECTs greater than –30 C (–22 F) (or heat loss rates less than 1750 W / m^2). The limiting surface temperature to protect exposed skin making incidental contact with the surfaces is –7 C (19 F). If the contact is prolonged (e.g., for tools), the limit is –1 C (30 F).

Manual dexterity of hands drops when there is uninterrupted work for 10–20 min at temperatures below 16 C (61 F).

General Controls

As with heat stress, general controls are actions that should be taken when workers may be exposed to cold stress. The general controls include training, hygiene practices, and medical surveillance.

TRAINING

When the air temperature may be below 5 C (41 F), the workers should be informed that cold stress may be a hazard, what is proper clothing, and that self-determination and cold stress hygiene should be practiced.

When work is performed at or below –12 C (10 F) ECT (Equivalent Chill Temperature), additional training topics include safe work practices and the recognition and first aid treatment of hypothermia and other cold-related disorders.

HYGIENE PRACTICES

Cold stress hygiene practices center around fluid replacement with warm, sweet, noncaffeinated drinks and self-determination. Warm drinks are palatable in cold stress and the fluid replacement is important because significant dehydration can

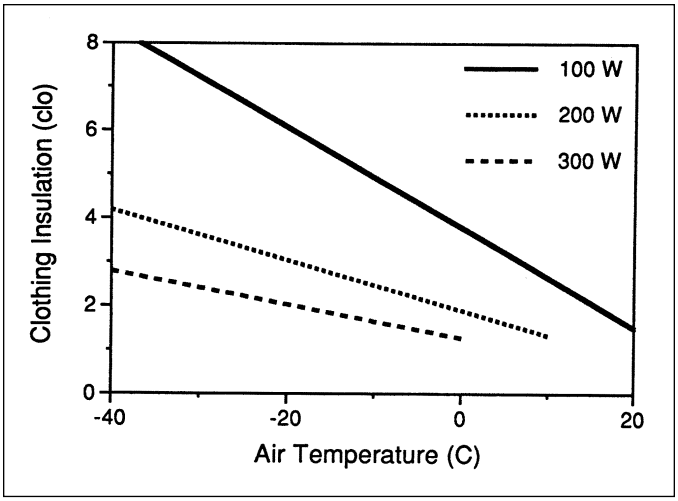

Figure 12–11. Estimation of clothing insulation (clo) required as a function of air temperature for different levels of work.

occur. Sweetened drinks provide a readily usable energy source to reduce the risk of fatigue. In addition, employees should be encouraged to eat a normal, balanced diet. If a worker experiences extreme discomfort or any of the symptoms of hypothermia (or any other cold-related disorder), the person should stop work and seek a place to rewarm.

Safe work practices include at least the following. In air temperatures below 2 C (36 F), anytime clothing becomes wet, it must be replaced immediately and the workers should be treated as if they are experiencing hypothermia. When handling liquids with boiling points below 4 C (39 F), special precautions should be taken that clothes do not become soaked in the liquid.

MEDICAL SURVEILLANCE

Medical certification is suggested for those who are routinely exposed below –24 C (–11 F) ECT. The certification should be based on a physical that considers fitness, weight, cardiovascular health, and other conditions that may affect cold-stress tolerance. Further, the personal-care physician should be consulted by any employee who is under care for chronic disease.

If there is reason to suspect that a person cannot properly thermoregulate, a medical restriction is appropriate in air temperatures below –1 C (30 F).

Specific Controls

ENGINEERING CONTROLS

Engineering controls attempt to reduce heat loss from the person as a whole or from exposed skin. Control includes increasing air temperature and decreasing air speed in the work zone, and providing rewarming areas. Specifically, engineering controls include the following:

- ➢ general or spot heating including hand warming
- ➢ hand warming for fine hand work below 16 C (61 F)
- ➢ minimize air movement (e.g., shielding, adjusting ventilation)
- ➢ reduce conductive heat transfer (e.g., no metal chairs or uninsulated tools)
- ➢ redesign equipment, process, etc. to control systemic and local cold stress
- ➢ provide warming shelters if exposures below –7 C (19 F)

ADMINISTRATIVE CONTROLS

Administrative controls attempt to reduce the exposure time, allow individual control over the work, and provide for mutual observation. Recommended administrative controls include the following:

- ➢ work/rest cycles
- ➢ schedule work to warmest times
- ➢ move work to warmer areas
- ➢ assign additional workers
- ➢ encouraging self-pacing and extra breaks if required
- ➢ buddy system, emphasizing mutual observation
- ➢ avoid long periods of sedentary effort
- ➢ allow for productivity reductions and extra effort from protective clothing
- ➢ provide an adjustment or conditioning period for new employees
- ➢ monitor weight changes for dehydration

PERSONAL PROTECTION

Because clothing is so important, personal protection is fundamental to managing cold stress. Clothing should be carefully selected in consultation with knowledgeable vendors and participation with the workers. The workers must be educated to the role of clothing items and what may compromise effectiveness. Some of these factors follow:

- ➢ properly selected insulated clothing
- ➢ wind-barriers
- ➢ special attention to feet, fingers, ears, nose and face
- ➢ gloves when air temperature is less than 16 C (61 F) for light work, 4 C (39 F) for moderate work and –7 C (19 F) for heavy work
- ➢ mittens when air temperature is less than –17 C (1 F)
- ➢ water-barriers to external liquids
- ➢ appropriate active warming systems (e.g., circulating air or liquids, electric)
- ➢ appropriate eye-protection for snow or ice-covered terrain

THERMAL COMFORT

Thermal comfort is "that condition of mind in which satisfaction is expressed with the thermal environment." Factors that affect thermal comfort include air temperature, humidity, air motion, surface temperatures, metabolic rate, and clothing. Age, sex, season, cultural background, and intraindividual variation play minor roles once the previously mentioned factors are accounted for. For instance, sex and seasonal changes in a comfortable environment can be

explained by differences in clothing. Factors that can disrupt a theoretically comfortable environment are asymmetric thermal radiation, drafts, vertical temperature gradients, and floor temperatures.

The ASHRAE Standard 55-1981 describes comfort zones based on operative temperature and humidity. These are illustrated in Figure 12–12. One zone is for the winter season and another, overlapping zone is for the summer season. The seasonal zones are specified to account for changes in clothing habits in the winter and summer. The operative temperature is approximately the globe temperature, and with little radiant heat it is the air (dry bulb) temperature.

Under ideal conditions, no more than 95 percent of the working occupants will be satisfied with the thermal environment. As the climatic conditions deviate from the "ideal," more people will be dissatisfied with the conditions. For those who wish to gain a better understanding of how a group of people will respond to an environment, the ISO has published a standard on thermal comfort. The standard considers such factors as climate, clothing, and metabolic rate.

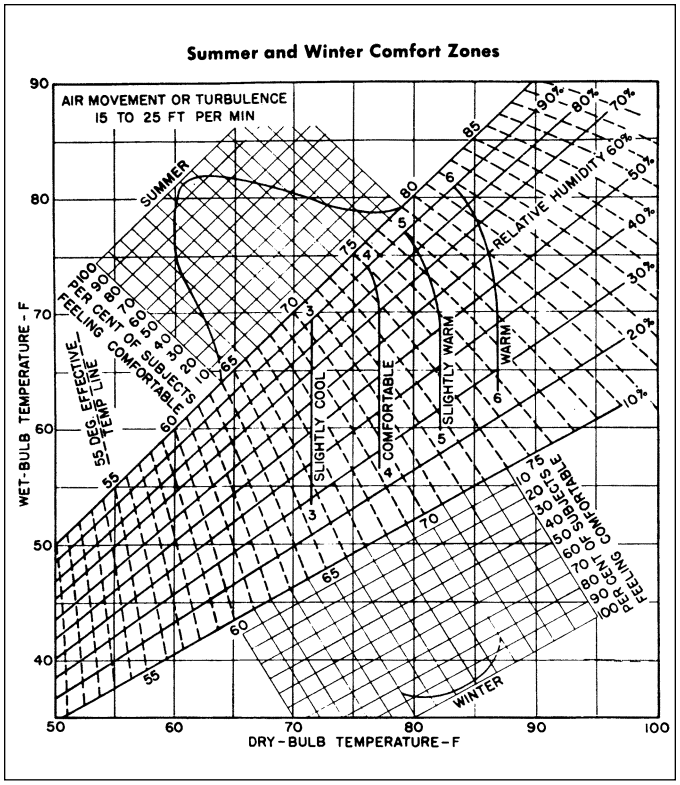

Figure 12–12. ASHRAE chart for comfort zones for sedentary activities. (Reprinted with permission from ASHRAE)

SUMMARY

This chapter was divided into three sections: heat stress, cold stress, and comfort. The heat stress and cold stress sections described methods to recognize that the stress may be present and significant in the workplace. Recognition is through types of work that are usually associated with the stress and the manifestations of disorders and worker behaviors due to the stress. Methods to evaluate the stress are then described with an emphasis on those recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) in the documentation of the Threshold Limit Values® (TLVs) for Heat and Cold Stress. Controls for heat and cold stress are then described in terms of general controls and specific controls.

General controls are broadly applicable when there is a potential for an excessive exposure. General controls include training, hygiene practices, and medical surveillance. With regard to training, annual sessions within the format for other health and safety training is encouraged. The content should include the nature of the hazard, when and how it may occur, the physiological responses, recognition of disorders related to the stress, hygiene practices, and proper use of personal protection and other controls.

Specific controls are those controls that are appropriate to a specific job and are selected based on the job and site constraints. They include the traditional hierarchy of controls: engineering controls, administrative controls, and personal protection.

Finally, means to evaluate thermal comfort were described. The parameters in the evaluation can be manipulated in order to improve the degree of comfort in the work environment.

ACKNOWLEDGEMENT

While direct reference is not made, many ideas in this chapter have been adopted from sources in the bibliography.

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Note: Some forms and spreadsheet-based analyses can be obtained as downloads from Stone Wheels on www.hsc.usf.edu/~tbernard

Chapter
13

Ergonomics

by Karl H. E. Kroemer, PhD, CPE

The terms ergonomics *and* human factors *(including* human engineering *and* human-factors engineering*) are in essence synonymous. They all indicate the application of scientific principles, methods, and data to the development of engineering systems in which people play a significant role.*

The word ergonomics *was coined in 1950 in the United Kingdom by a group of physical, biological, and psychological scientists and engineers to describe their interdisciplinary efforts to design equipment and work tasks so that they fit the operator. The term is derived from the Greek-language word roots* ergon*, (human) work and strength, and* nomos*, indicating law or rule. In 1957, U.S. behavioral scientists, anthropometrists, and engineers working in this emerging discipline decided to call their new professional association the Human Factors Society. The words "and Ergonomics" were inserted in 1992.*

DEFINITION OF ERGONOMICS

Ergonomics is the study of human characteristics for the appropriate design of the living and work environment. Ergonomic researchers strive to learn about human characteristics (capabilities, limitations, motivations, and desires) so that this knowledge can be used to adapt a human-made environment to the people involved. This knowledge may affect complex technical systems or work tasks, equipment,

and workstations, or the tools and utensils used at work, at home, or during leisure times. Hence, ergonomics is human-centered, transdisciplinary, and application-oriented.

The goals of ergonomics range from the basic aim of making work safe through increasing human efficiency to the purpose of creating human well-being. The National Research Council (1983) stated that human factors engineering can be defined as the application of scientific principles, methods, and data drawn from a variety of disciplines to the development of engineering systems in which people play a significant role. We measure successful application by improved productivity, efficiency, safety, and acceptance of the resultant system design. The disciplines that can be applied to a particular problem include psychology, cognitive science, physiology, biomechanics, applied physical anthropology, and industrial and systems engineering. The systems range from the use of a simple tool by a consumer to multiperson-sociotechnical systems. They typically include both technological and human components.

The National Research Council said (1983): "Human factors specialists are united by a singular perspective on the system design process: that design begins with an understanding of the user's role in overall system performance and that systems exist to serve their users, whether they are consumers, system operators, production workers, or maintenance crews. This user-oriented design philosophy acknowledges human variability as a design parameter."

Figure 13–1 shows how ergonomics interacts with related applied disciplines and sciences. Among the primary foundations of ergonomics are the biological sciences, particularly anatomy and physiology. Leonardo da Vinci in the 16th century, Giovanni Alfonso Borelli in the 17th century, Lavoisier, Amar, Rubner, Johannson, and many others in the 19th and early 20th centuries contributed ideas, concepts, theories, and practical data to forward the understanding of the role of the human body in a work environment. Among the social and behavioral sciences, anthropologists, psychologists, and sociologists have contributed to modeling and understanding the human role in societal and technological systems, including management theories. Among the engineering disciplines, industrial engineers (using, for example, the groundwork laid by Frederick Taylor and the Gilbreths), mechanical and computer engineers, and designers are the major users of ergonomic knowledge. A typical application is in computer-aided design (CAD), which incorporates the systematic consideration of human attributes, especially anthropometric and biomechanical information. Ergonomists have developed their own theories, methods, techniques, and tools to perform scientific research. Formal college degree curricula are offered by many universities, usually in departments of industrial engineering or psychology. Productivity, health, and safety at work, the quality of work life, and participatory management are some well-known programmatic aspects of ergonomics.

There are three levels at which ergonomic knowledge can be used.

- ➢ *Tolerable* conditions do not pose known dangers to human life or health.
- ➢ *Acceptable* conditions are those upon which (according to the current scientific knowledge and under given sociological, technological, and organizational circumstances) the people involved can voluntarily agree.
- ➢ *Optimal* conditions are so well adapted to human characteristics, capabilities, and desires that physical, mental, and social well-being is achieved.

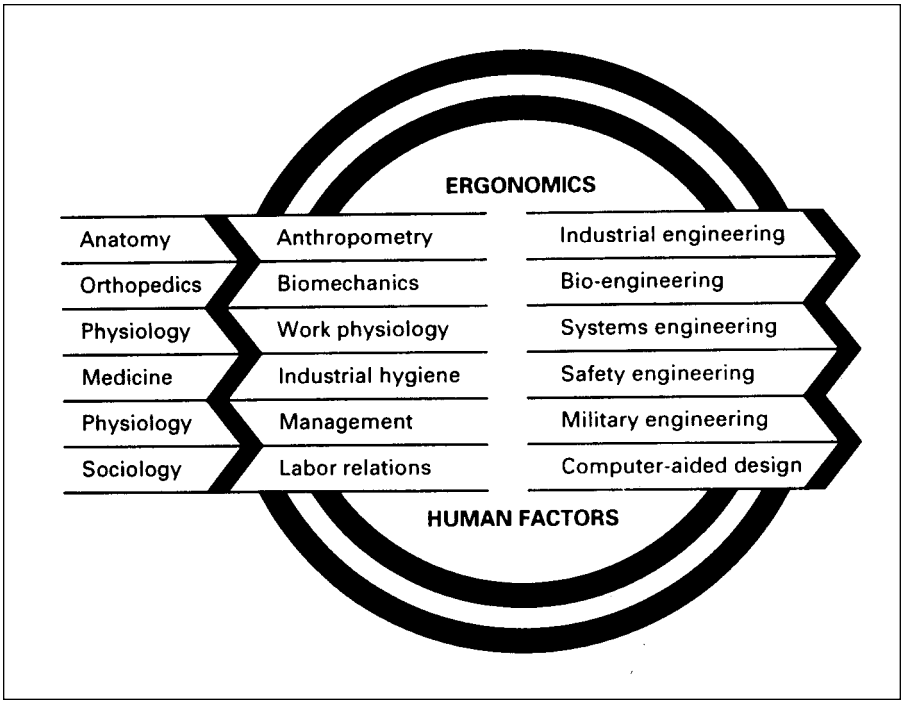

Figure 13–1. Origins and applications of ergonomics/human factors.

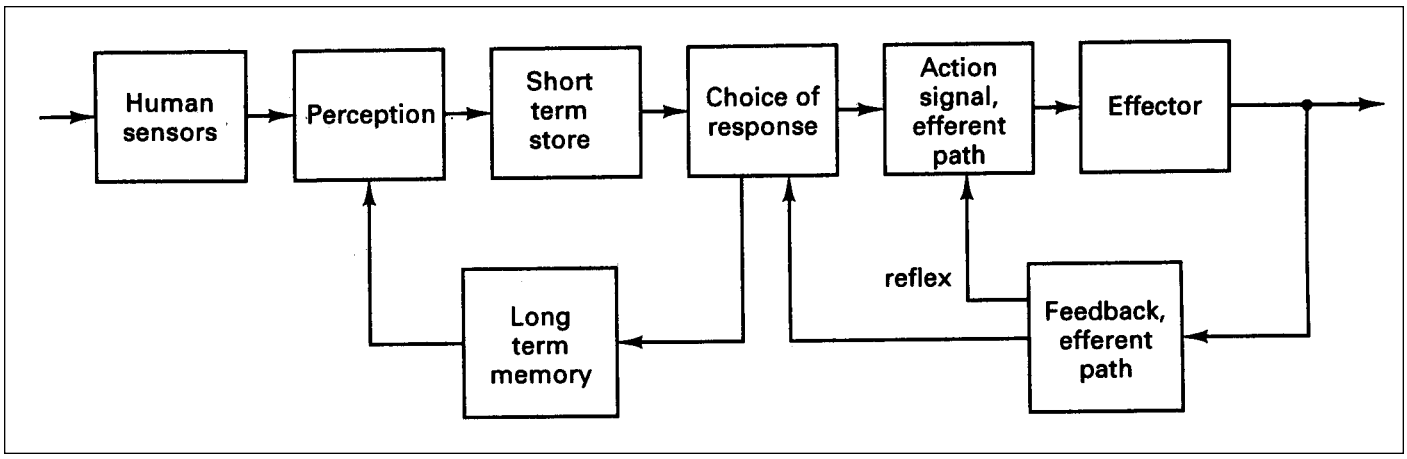

Figure 13–2. The human as energy or information processor. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency.* Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

The aim of ergonomics/human engineering is to achieve ease and efficiency at work.

MATCHING PERSON AND TASK

People perform widely differing tasks in daily work situations. These tasks must be matched with human capabilities to avoid *underloading*, in which human capabilities are not sufficiently used, as well as *overloading*, which may cause the employee to break down and suffer reduced performance capability or even permanent damage. Engineering psychologists, work physiologists, and occupational biomechanists evaluate the capacities and limitations of the worker to perform work; they also determine human tolerance to stresses produced by the environment.

THE HUMAN AS INFORMATION PROCESSOR

In the traditional system concept of engineering psychology, the human is considered a receptor and processor of information or energy, who then outputs information or energy. Input, processing, and output follow each other in sequence. The output can be used to run a machine, which may be a simple hand tool or a space craft. This basic model is depicted in Figure 13–2.

The actual performance of this *human-technology* system (in the past often called a man-machine system) is monitored and compared with the desired performance. Hence, feedback loops connect the output side with the input side. The difference between output and input is registered in a comparator, and corrective actions are taken to minimize any output/input difference. In this system, the human controls, compares, makes decisions, and corrects.

Affordance is the property of an environment that has certain values to the human. An example is a stairway that affords passage for a person who can walk but not for a person confined to a wheelchair. Thus, passage is a property of the stairway, but its affordance value is specific to the user. Accordingly, ergonomics or human engineering provides affordances.

Traditional engineering psychologists describe our activities as a linear sequence of stages, from perception to decision to response. Research is done separately on each of these stages, on their substages, and on their connections. Such independent, stage-related information is then combined into a linear model.

Ecological psychologists believe that this linear model is invalid; they consider human perception and action to be based on simultaneous rather than sequential information. This concept requires fundamentally new models of information, cognition, and performance assessment. Yet, current behavioral knowledge is still almost completely based on the traditional sequential-system concept.

The Nervous System

Anatomically, one divides the nervous system into the following three major subdivisions.

- ➢ The *central nervous system* (CNS) includes brain and spinal cord; it has primarily control functions.
- ➢ The *peripheral nervous system* (PNS) includes the cranial and spinal nerves; it transmits signals to and from the CNS, but usually does not control.
- ➢ The *autonomic nervous system* consists of the sympathetic and the parasympathetic subsystems, which regulate involuntary functions, such as of smooth and cardiac muscle, blood vessels, digestion, and glucose release in the liver. The autonomic system is not under conscious control.

Functionally, there are two subdivisions of the nervous system: the autonomic system (just discussed), and the *somatic* (Greek: *soma*, body) nervous system that controls mental activities, conscious actions, and skeletal muscle.

The brain is usually divided into *forebrain*, *midbrain*, and *hindbrain*. Of particular interest for the neuromuscular con-

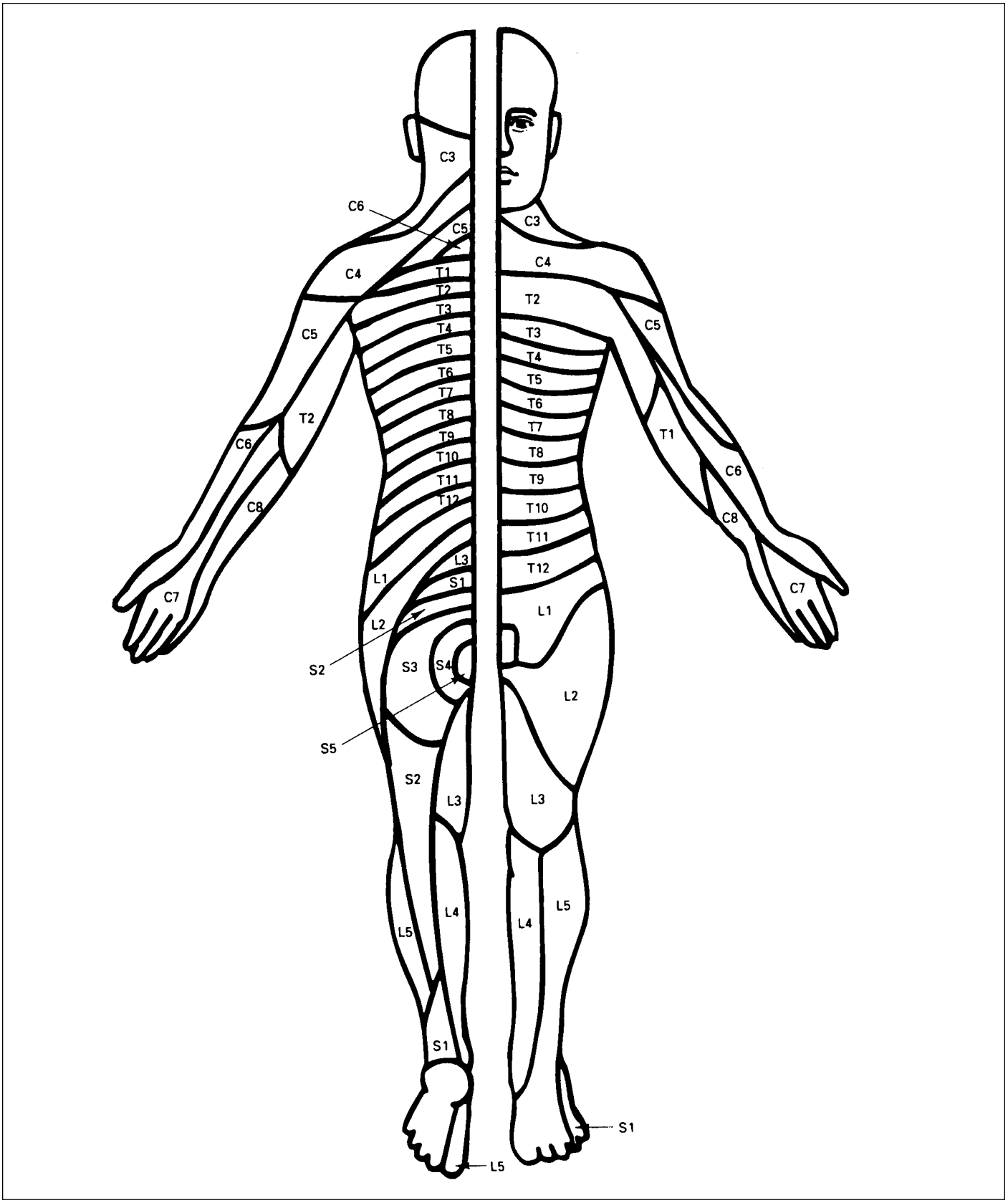

Figure 13–3. Regions of the body innervated by nerves eminating from sections of the spinal column. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency*. Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

trol system is the forebrain with the cerebrum, which consists of the two (left and right) cerebral hemispheres, each divided into four lobes. Control of voluntary movements, sensory experience, abstract thought, memory, learning, and consciousness is located in the cerebrum. The multifolded *cortex* enwraps most of the cerebrum. The cortex controls voluntary movements of the skeletal muscle and interprets sensory inputs. The *basal ganglia* of the midbrain are composed of large pools of neurons, which control semivoluntary complex activities such as walking. Part of the hindbrain is the *cerebellum*, which integrates and distributes impulses from the cerebral association centers to the motor neurons in the spinal cord.

The *spinal cord* is an extension of the brain. The uppermost section of the spinal cord contains the 12 pairs of *cranial nerves*, which serve structures in the head and neck, as well as the lungs, heart, pharynx, and larynx, and many abdominal organs. They control eye, tongue, and facial movements, and the secretion of tears and saliva. Their main inputs are from the eyes, the tastebuds in the mouth, the nasal olfactory receptors, and touch, pain, heat, and cold receptors of the head. Thirty-one pairs of *spinal nerves* pass out between the appropriate vertebrae and serve defined sectors of the rest of the body. Nerves are mixed sensory and motor pathways, carrying both somatic and autonomic signals between the spinal cord and the muscles, articulations, skin, and visceral organs. Figure 13–3 shows how the spinal nerves emanating from sections of the spinal column ("spinal nerve roots") innervate defined areas of the skin (*dermatomes*).

Sensors

The central nervous system receives information from internal receptors, *interoceptors*, which report on changes within the body; on digestion, circulation, excretion, hunger, thirst, sexual arousal, and feeling well or sick. *Exteroceptors* respond to light, sound, touch, temperature, electricity, and chemicals. Since all of these sensations come from various parts of the body (Greek, *soma*), external and internal receptors together are also called *somesthetic sensors*.

Internal receptors include the *proprioceptors*. Among these are the muscle spindles, nerve filaments wrapped around small muscle fibers that detect the amount of stretch of the muscle. Golgi organs are associated with muscle tendons and detect their tension, and hence report to the central nervous system information about the strength of contraction of the muscle. Ruffini organs are kinesthetic receptors located in the capsules of articulations. They respond to the degree of angulation of the joints (joint position), to change in general, and also to the rate of change.

The *vestibular sensors* are also proprioceptors. They detect and report the position of the head in space and respond to sudden changes in its attitude. To relate the position of the body to that in the head, proprioceptors in the neck are triggered by displacements between the trunk and head.

Another set of interoceptors, called *visceroceptors*, reports on the events within the visceral (internal) structures of the body, such as organs of the abdomen and chest, as well as on events within the head and other deep structures. The usual modalities of visceral sensations are pain, burning sensation, and pressure.

External receptors provide information about the interaction between the body and the outside: sight (vision), sound (audition), taste (gustation), smell (olfaction), temperature, electricity, and touch (taction). The sensations of touch, sight, and sound can be used as feedback to the body regarding the direction and intensity of muscular activities transmitted to an outside object. Free nerve endings, Meissner's and Pacinian corpuscles, and other receptors are located throughout the skin of the body, however, in different densities. They transmit the sensations of touch, pressure, and pain. Since the nerve pathways from the free endings interconnect extensively, the sensations reported are not always specific for a modality; for example, very hot or cold sensations can be associated with pain, which may also be caused by hard pressure on the skin.

Since the pathways of interoreceptors and externoreceptors are closely related and anatomically intertwined, information about the body is often integrated with information about the outside.

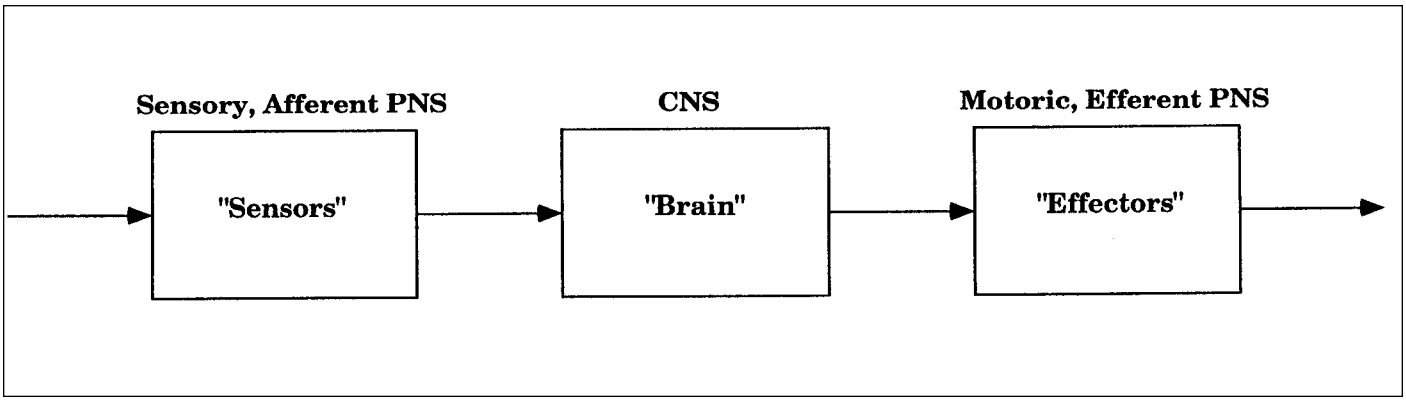

Figure 13–4. The human as receptor, processor, and generator of signals.

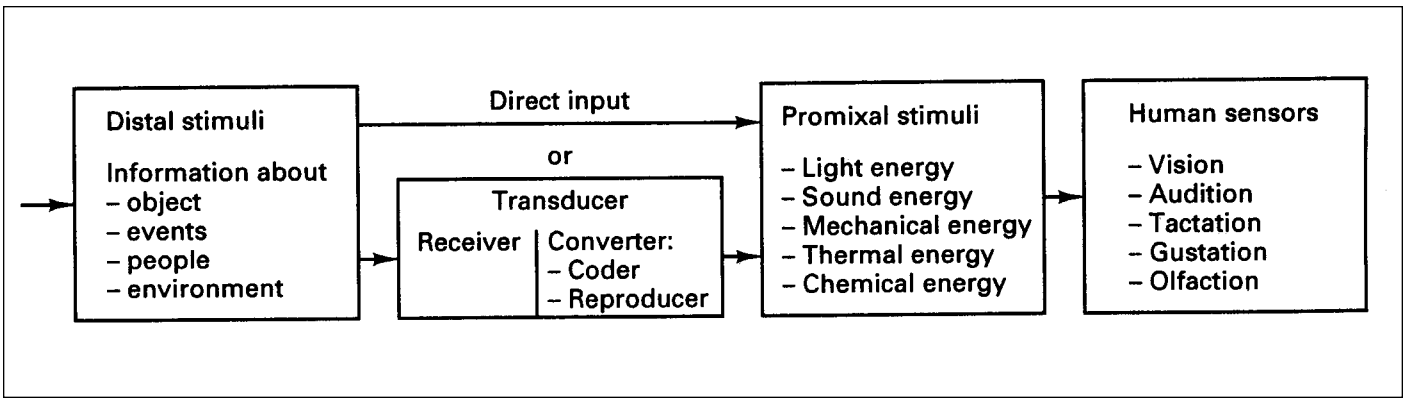

Figure 13–5. Input from distal and proximal stimuli to human sensors. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency.* Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

The "Signal Loop"

Following the traditional concept, one can model the human as a processor of signals in some detail, as shown in Figure 13–4. Information (energy) is received by a sensor and impulses sent along the afferent (sensory) pathways of the PNS to the CNS. Here, the signals are perceived and compared with information stored in the short-term or long-term memories. The signal is processed in the CNS and an action (including "no action") is chosen. Appropriate action (*feedforward*) impulses are generated and transmitted along the afferent (motor) pathways of the PNS to the *effectors* (voice, hand, etc.). Of course, many feedback loops exist.

Both sides of the processor model can be analyzed further, as shown in Figure 13–5. Information is provided by *distal stimuli*—but to be sensed, they must appear in a form to which human sensors can respond; it must have suitable qualities and quantities of electromagnetic, mechanical, electrical, or chemical energy. If the distal events do not present *proximal stimuli* that can be sensed directly, the distal information must be transformed into energy that can trigger human sensations. For this, *transducers* are designed by the human factors specialist: for example, a sound, a light, or a signal of some kind on a computer screen can serve as transducer.

On the output side, the actions of the human effector (such as hand, foot, or voice box) may directly control a machine or process, or one may need another transducer; for example, auxiliary power may amplify movement of a control effected by the human hand (e.g., "power steering" in an automobile). Figure 13–6 portrays the model. Of course, recognizing the need for a transducer and providing information for its suitable design is again a primary task of the human-factors engineer.

Responding To Stimuli

The time passing from the appearance of a proximal stimulus (for example, a light) to the beginning of an effector action (such as moving a foot) is called *reaction time*. The additional time to perform an appropriate movement (for instance, stepping on a brake pedal) is called *motion* or *movement* time. Motion time added to reaction time results in the *response time*. (Note that, in everyday use, these terms are often not clearly distinguished.)

Experimental analysis of reaction time goes back to the very roots of experimental psychology: many of the basic results were obtained in the 1930s, with additional experimental work done in the 1950s and 1960s. Innumerable experiments have been performed, hence, many tables of such times have been published. In engineering handbooks, some of these apparently have been consolidated from various sources; however, the origin of the data, the experimental conditions (for example, the intensity of the stimulus) under which they were measured, the measuring accuracy, and the subjects participating are no longer known.

The following table is typical of generally used but fairly dubious reaction time information, often applied without much consideration or confidence:

electric shock:	130 ms
touch, sound:	140 ms
sight, temperature:	180 ms
smell:	300 ms
taste:	500 ms
pain:	700 ms

While accepting the experience that, in real-life situations, the times may be considerably longer, there appears to be little difference in reactions to electrical, tactile, and sound stimuli. The slightly longer times for sight and temperature sensations may be well within the measuring accuracy, or within the variability among persons. However, the time following a smell stimulus is distinctly longer, and the time for taste again longer, while it takes by far the longest to react to the infliction of pain.

If a person knows that a particular stimulus will occur, is prepared for it, and knows how to react to it, the resulting reaction time (RT) is called *simple reaction time*. Its duration depends on the stimulus modality and the intensity of the stimulus. If one of several possible stimuli occurs, or if the person has to choose between several possible reactions, one speaks of "choice reaction time." *Choice reaction time* is a

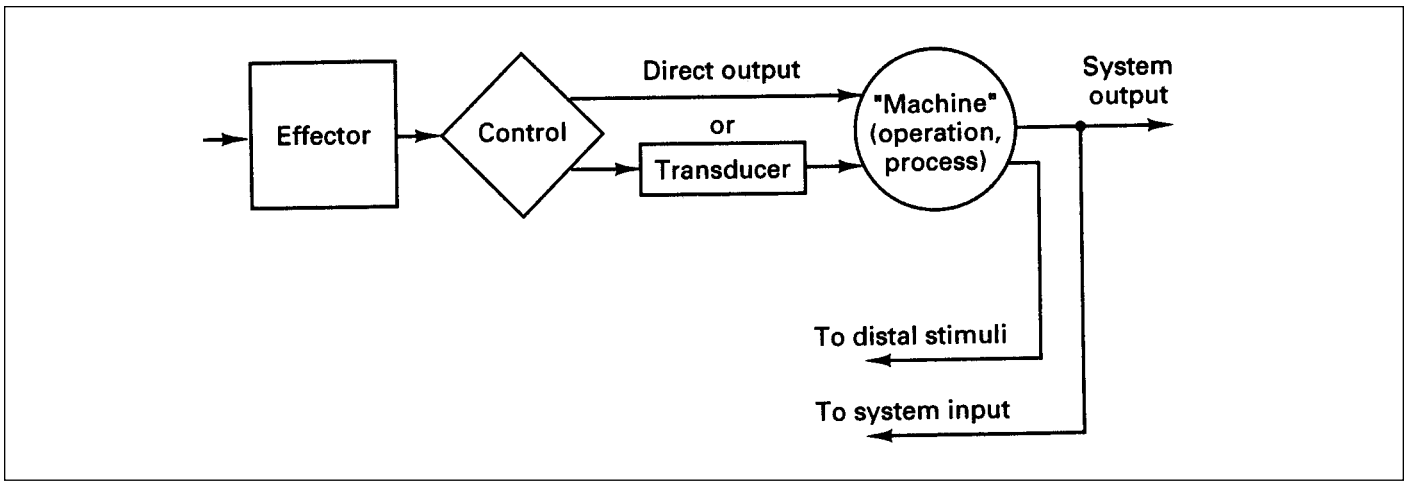

Figure 13–6. Effector outputs of the human, and feedback origins. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency*. Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

logarithmic function of the number of alternative stimuli and responses:

$$RT = a + b \log_2 N \quad (1)$$

with a and b empiric constants and N the number of choices. N may be replaced by the probability $p = 1/N$ *of any particular alternative:*

$$RT = a + b \log_2 p^{-1} \text{ (the Hick-Hyman equation)} \quad (2)$$

Under optimal conditions, simple auditory, visual, and tactile reaction times are about 0.2 seconds. If conditions deteriorate, such as uncertainty about the appearance of the signal, reaction slows. For example, simple reaction time to tones near the lower auditory threshold may increase to 0.4 seconds. Similarly, visual reaction time is dependent on intensity, size, and flash duration of the stimulus. Reactions to visual signals in the periphery of the visual field (such as 45 degrees from the fovea) are about 15 to 30 ms slower than to centrally located stimuli (Boff & Lincoln, 1988).

Reaction times of different body parts to tactual stimuli vary only slightly, within about 10 percent, for finger, forearm, and upper arm. Reaction time slows if it is difficult to distinguish between several stimuli that are quite similar, but only one should trigger the response. Also, reaction time increases if one has to choose between several possible responses to one signal—as described by the Hick-Hyman formula. Simple reaction time changes little with age from about 15 to 60 years, but is substantially slower at younger ages and slows moderately as one grows old.

Motion time follows reaction time. Movements may be simple, such as lifting a finger in response to a stimulus, or complex, such as swinging a tennis racket. Swinging the racket contains not only more complex movement elements, but also larger body and object masses that must be moved, which takes time. Movement time also depends on the distance covered and on the precision required. Related data are contained in many systems of time and motion analyses, often used in industrial engineering.

These relations have been expressed in a Motion Time (MT) equation called Fitts' Law:

$$MT = a + b \log_2 (2D / W) \quad (3)$$

D is the distance covered by the movement, and W is the width of the target. The expression $\log_2 (2D/W)$ is often called *Index of Difficulty*. The constants a and b depend on the situation, such as body parts involved, masses moved, tools or equipment used, on the number of repetitive movements, and on training.

The reduction of response time, the sum of the reaction and motion lags, is a common engineering goal. It can be achieved by optimizing the stimulus and selecting the body member that is best suited to the task. The best proximal signal is the one that is received quickly (primarily according to modality and intensity) and is different from other signals. Afferent and efferent transmission depend on the composition, diameter, and length of nerve fibers and on synaptic connections; practically, the ergonomist usually selects the shortest transmission distance. Yet the best chances for reducing delays are in the processing time needed in the central nervous system for perceptual tasks such as the detection, identification, and recognition of the signal and for cognitive tasks like deciding and planning. Thus, a clear signal leading to an unambiguous choice of action is the most efficient approach to reducing delays.

Choosing the most suitable body member for the fastest response includes making sure that the minimal segment mass must be moved. Thus, moving an eye is faster than moving a finger, which is faster than moving a leg.

HUMAN CAPACITY FOR WORK

Of course, individuals differ from each other in their capacities to perform tasks. Thus, the workload imposed by a given task differs from person to person; also, the workload may depend on the temporal state of an individual—for example on training, fatigue, and motivation.

The assessment of a workload, whether psychological or physical, commonly relies on the "resource construct." It assumes that there is a given (measurable) quantity of capability and attitude available, a known (or unknown) portion of which is demanded by the job. (See Figure 13–7.) Accordingly, workload is often defined as the portion of the maximal performance capacity that is expended in performing a given task.

Following this concept, one should obviously avoid any condition in which more is demanded from the operator than he or she can give. Otherwise, an *overload* condition results: the performance of the task will not be optimal and the operator is likely to suffer, physically or psychologically, from the overload. However, a task demand that is below the operator's capacity leaves a residual capacity. Its measurement provides an assessment of the actual workload. (Note that using too little of a person's capacity creates an *underload* with negative effects of its own, such as boredom.)

More complex models have been proposed—for example, a multiple-resource model in which separate reservoirs are postulated, such as for stages of information processing (afferent, central, and efferent), codes of processing (eg, verbal or spatial), and input/output modalities (visual, auditory or verbal, and manual).

Properties of Workload Measures

Metrics to assess workload should meet the following requirements.

- ➢ Diagnosticity: How precisely is the nature of the load revealed?
- ➢ Sensitivity: How well is a change in workload detected?
- ➢ Intrusiveness: Does the measurement interfere with task performance?
- ➢ Validity: Does the metric measure what it is supposed to?
- ➢ Reliability: Is the metric stable and consistent over time, i.e., repeatable?
- ➢ Operator acceptance
- ➢ Ease of use

Human Capacity for Mental Work

Common sense and general understanding make the distinction between physical (physiological) and mental (psychological) workload obvious and, in that juxtaposition, explain the meaning of both. Yet, as Tsang and Wilson (1997) state, there is no distinct, universally accepted definition of mental workload. In fact, its meaning has shifted and changed. During World War II, attention was of predominant interest, which was followed by concern about information processing and cognitive issues as human-operated systems became increasingly complex. With more internal automation, the system demands on the operator shifted to supervisory control responsibility, situation awareness and strategic task management. However, these concepts do not completely replace, nor totally encompass, each other. Criteria that have been developed for classic workload metrics also apply to measurement of situation awareness in complex environments, even though the two load concepts are not interchangeable.

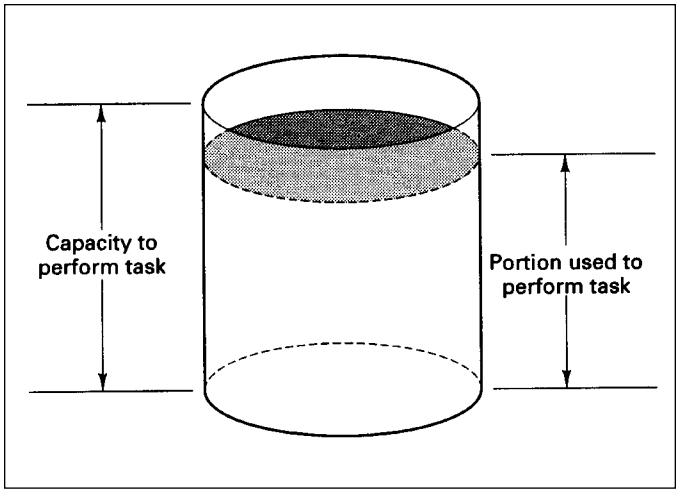

Figure 13–7. The "resource model". Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency.* Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

Measuring Mental Workload

We can use four different approaches to empirically assess mental workload. Three rely on objective measures: of primary-task performance, of secondary-task performance, and of physiological events. The other measurement uses subjective assessments. Measures of task performance, as well as of subjective assessment, presume that both *zero* and *full* capacities are known, since they assess the portion of capacity loading.

The fourth empirical approach to measure workload relies on the measurement of the primary-task performance by observing how *noncritical* components of the primary task are performed. The hypothesis is that, as the workload increases, performance changes measurably. Candidates for such unobtrusive measures are the status of a person's speech, the depletion of stock, disorder, or clutter at the workplace, and the length of a line of customers. Such embedded measures of workload would not add to the task at hand. The following are examples of secondary tasks employed in measuring workload:

- ➢ Simple reaction time—draws on perceptual and response execution resources.
- ➢ Choice reaction time—same as for simple reaction time, but with greater demands.
- ➢ Tracking—requires central processing and motor resources, depending on the order of control dynamics.

- ➢ Monitoring of the occurrence of stimuli—draws heavily on perceptual resources.
- ➢ Short-term memory tasks—heavy demand on central-processing resources.
- ➢ Mathematics—draws most heavily on central-processing resources.
- ➢ Shadowing—subject repeats verbal or numerical material as presented: Heaviest demands on perceptual resources.
- ➢ Time estimations—(a) subject estimates time passed: Draws upon perceptual and central processing resources; (b) subject indicates sequence of regular time intervals by motor activity: Makes large demands on motor output resources.

Physiological measures, especially heart rate, eye movements, pupil diameter, and muscle tension can often be measured without intruding on the primary task. However, these measures may be insensitive to the task requirements or may be difficult to interpret.

Subjective assessments are a common means to assess mental workload. Humans are able to internally integrate the demands of the task, and to make statements about the perceived demand, often in terms of ratings and rankings. However, the subjective assessment of the perceived workload may be unreliable, invalid, or inconsistent with other performance measures. If subjective measures are taken after the task has been completed, they are not real-time evaluations; on the other hand, if performed during the task, they may intrude on the task.

Several pragmatic measures of the workload have been widely used, even though they have been criticized on both theoretical and technical grounds (Tsang & Wilson 1997). Prominent among them are the modified Cooper-Harper scale (Wierwille et al, 1985), the overall workload scale (OW, Tsang & Wilson 1997), the NASA task load index (TLX, Hart & Staveland 1988), and the subjective workload assessment technique (SWAT, Colle & Reid 1998). The first two are unidimensional rating scales; the last two are subjective techniques using multidimensional scales. While there are good theoretical and statistical reasons for using the TLX, SWAT, and OW, they are more complex to administer than the Cooper-Harper scale, which is fairly self-explanatory.

Human Capacity for Physical Work

An individual's capacity for physical work is usually determined by the limits of his or her respiratory and cardiovascular systems to deliver oxygen to the working muscles, and by the limits of the metabolic system to use chemically stored energy to do muscular work. *Maximal oxygen uptake* often is used to describe the upper limit of the aggregate capacity. Tolerance times for maximal efforts are measured in hours and minutes, even in seconds for a sprint runner. In a modern industrial setting, maximal effort may be required for brief periods, such as when an employee must heave heavy loads onto a hand truck; but during an eight-hour shift, the average energy required usually falls well below human peak capacity.

The biochemical steps to transform foodstuffs into energy available for work are quite complex; some are anaerobic, but, altogether, the process is aerobic. Consequently, measurement of the volume of oxygen consumed provides an overall index of energy consumption and hence of the energy demands of work. Use of one liter (L) of oxygen yields approximately five kilocalories (kcal or Cal; equivalent to about 21 kiloJoules, kJ). To put oxygen consumption and energy demands into proper perspective, consider that a trained athlete may reach a maximal oxygen uptake of 6 L/min. Aside from a person's physique and training, age and gender influence the oxygen intake capacity substantially. Men in their 20s have an average maximal capacity of 3–3.5 L/min; women of the same age have an average capacity of 2.3–2.8 L/min. At age 60, the capacities commonly diminish to about 2.2–2.5 L/min for men, and 1.8–2.0 L/min for women. As with most physiological characteristics, there is considerable individual variability.

Energy Cost of Work

Industrial jobs seldom demand continuous energy expenditure close to the maximum over the course of a workday. Rest pauses, fetching tools, mopping the brow, and receiving instruction reduce the average energy expenditure considerably. Table 13–A lists several typical activities and their average metabolic costs; resting values are included for reference. The given values must be adjusted according to one's body weight; the table applies to a man of 70 kg (155 lb). Other tables published in the physiological literature may be in different units (Calories, Joules, Btu; per hour or minute), and may or may not include basal rates—be careful to use these tables correctly.

Many jobs consist of intermittent tasks of different energy requirements. The total metabolic expenditure for the job may be calculated using the following formula:

$$M = M_1 t_1 + M_2 t_2 + \ldots M_n t_n \qquad (4)$$

In this formula, M is the total metabolic energy cost, $M_1 \ldots Mn$ are the metabolic costs of individual tasks; $t_1 \ldots tn$ indicate the durations of each individual task. Using the values listed in Table 13–A, an example of estimating energy expenditures during the day is shown in Table 13–B.

There is close interaction between the human circulatory and metabolic systems. Nutrients and oxygen must be brought to the working muscles and metabolic by-products removed from them to ensure proper functioning. Therefore, heart rate (which is an important indicator of circulatory functions) and oxygen consumption (representing the metabolic processes taking place in the body) have a linear and reliable relationship in the range between light and heavy work. (However, when very light work or extremely heavy work is done, that relationship may not be stable. It is also not reliable under severe environmental conditions or when workers are under mental stress.) Assuming such a linear relationship, one can often simply substitute heart-rate

Table 13–A. ***Metabolic Energy Costs of Several Typical Activities***

Activity	*kcal/h*	*Btu/h*
Resting, prone	80–90	320–360
Resting, seated	95–100	375–397
Standing, at ease	100–110	397–440
Drafting	105	415
Light assembly (bench work)	105	415
Medium assembly	160	635
Driving automobile	170	675
Walking, casual	175–225	695–900
Sheet metal work	180	715
Machining	185	730
Rock drilling	225–550	900–2,170
Mixing cement	275	1070
Walking on job	290–400	1,150–1,570
Pushing wheelbarrow	300–400	1,170–1,570
Shoveling	235–525	930–2,070
Chopping with axe	400–1,400	1,570–5,550
Climbing stairs	450–775	1,770–3,070
Slag removal	630–750	2,500–2,970

Values are for a male worker of 70 kg (154 lb). (Reprinted with permission from "Ergonomics guide to assessment ot metabolic and cardiac costs of physical work." *American Industrial Hygiene Association Journal,* 32: 560–564, 1971.)

recording for measurement of oxygen consumption. This is a very attractive shortcut, since heart rate can be recorded rather easily. Heart rate reacts faster to work demands and therefore more easily indicates quick changes in body functions due to changes in work requirements.

The simplest technique for heart-rate assessment is to palpate an artery, often in the wrist. The measurer counts the number of heartbeats over a given period of time—such as 15 seconds—and then calculates the average heart rate per minute. More refined methods use various plethysmographic techniques, which rely on the deformation of tissue that results when imbedded blood vessels fill with blood with each pulse. More expensive techniques rely on electric signals that are associated with the contractions of the heart. When using this technique, electrodes are usually placed on the person's chest.

Instead of measuring a person's reactions to actual job loads, it is often desired to determine the individual's capabilities using standardized loadings in the laboratory. Bicycle ergometers, treadmills, or steps are commonly used to simulate stressful job demands. The reactions of the individual in terms of oxygen consumption, heart rate, and blood pressure are used to assess that person's ability to meet or exceed such demands. However, the examining physician needs to know what the actual work demands are. The industrial hygienist may be called upon to help in the assessment of the existing work demands.

For more information on the assessment of physical work capacity and of energy cost of work, consult the texts by Astrand and Randahl (1986), Eastman Kodak (1983, 1986), Bernhard and Joseph (1994), Kinney (1980), Kroemer et al (1997, 2001), Mellerowicz and Smodlaka (1981), and the *Ergonomics Guides* published by the American Industrial Hygiene Association (AIHA).

Table 13–B. ***Example of Energy Expenditure During Leisure and at Work***

		Energy Cost	
Activity	*Duration (h)*	*kcal/h*	*kcal/Duration*
Sleeping	8	85	680
Sitting, resting	4.5	100	450
Walking	1.5	170	255
Driving automobile	1	200	200
Subtotal for leisure	15		1,585
Work, light assembly	7	105	735
Work, walking	1	200	200
Work breaks, sitting	1	100	100
Subtotal for work	9		1,035
Total per day	24		2,620

Classification of Work

The work demands listed in Table 13–C are rated from light to extremely heavy in terms of energy expenditure per minute, and the relative heart rate in beats per minute is also given. Light work is associated with rather small energy expenditures and is accompanied by a heart rate of approximately 90 beats/min. At this level of work, the energy needs of the working muscles are supplied by oxygen available in the blood and by glycogen in the muscle. There is no buildup of lactic acid or other metabolic by-products that would limit a person's ability to continue such work.

At medium work, which is associated with about 100 heart beats/min, the oxygen required by the working muscles is still covered, and lactic acid developed initially at the beginning of the work period is re-synthesized to glycogen during the activity.

In heavy work, during which the heart rate is about 120 beats/min, the oxygen required is still supplied if the person is physically capable to do such work and specifically trained

Table 13–C. ***Classification of Light to Heavy Work According to Energy Expenditure and Heart Rate***

Classification	*Total Energy Expenditure (kcal/min)*	*Heart Rate (beats/min)*
Light work	2.5	90 or less
Medium work	5	100
Heavy work	7.5	120
Very heavy work	10	140
Extremely heavy work	15	160 or more

in this job. However, the lactic acid concentration produced during the initial phase of the work is not reduced but remains high until the end of the work period. The concentration returns to normal levels after cessation of the work.

In the course of light, medium, and, if the person is capable and trained, even heavy work, the metabolic and other physiological functions can attain a steady-state condition during the work period. This indicates that all physiological functions can meet the demands and will remain essentially constant throughout the duration of the effort.

However, no steady state exists in the course of very heavy work, during which the heart rate level attains or exceeds 140 beats/min. In this case, the original oxygen deficit incurred during the early phase of the work increases throughout the duration of the effort and metabolic by-products accumulate. This accumulation makes intermittent rest periods necessary, sometimes even forcing the person to stop this effort completely. At even higher energy expenditures, which are associated with heart rates of 160 beats/min or more, the lactic acid concentration in the blood and the oxygen deficit achieve such magnitudes that frequent rest periods are needed. Even highly trained and capable persons are usually unable to perform such a demanding job throughout a full working day.

Hence, energy requirements or heart rate allow one to judge whether a job is energetically easy or hard. Of course, such labels as light, medium, or heavy reflect judgments of physiological events (and of their underlying job demands) that rely very much on the current socioeconomic concept of what is comfortable, acceptable, permissible, difficult, or excessive.

Rating the perceived effort is another way to classify work demands. We are all able to perceive the strain generated in our body by a given work task and we can make absolute and relative judgments about this perceived effort. Around the middle of the 19th century, Weber and Fechner described models of the relationship between physical stimulus and the perceptual sensation of that stimulus, i.e., the *psychophysical correlate*. Weber suggested that the "just noticeable difference" that can be perceived increases with the absolute magnitude of the physical stimulus *I:*

$$\Delta I = \alpha \bullet I \qquad (5)$$

with α a constant.

In the 1950s, Stevens at Harvard and Ekman in Sweden introduced ratio scales, which assume a zero point and equidistant scale values. These scales have since been used to describe the relationships between the perceived intensity and the physically measured intensity of a stimulus in a variety of sensory modalities (e.g., related to sound, lighting, and climate) as follows:

$$P = \beta .\ I^n \qquad (6)$$

where β is a constant, and n ranges from 0.5–4.

Since the 1960s, Borg and his co-workers have modified these relationships to take deviations from previous assumptions (such as zero point and equidistance) into account and to describe the perception of different kinds of physical efforts (Borg, 1982, 1990). Borg's "general function" is as follows:

$$P = a + c\ (I + b)^n \qquad (7)$$

In the formula, the constant a represents "the basic conceptual noise" (normally less than 10% of I), and the constant b indicates the starting point of the curve; c is a conversion factor that depends on the type of effort.

Ratio scales indicate proportions between percentages but do not indicate absolute intensity levels; they neither allow intermodal comparisons nor comparisons between intensities perceived by different individuals. Borg has tried to overcome this problem by assuming that the subjective range and intensity level are about the same for each subject at the level of maximum intensity. In 1960, this led to the development of a category scale for rating the perceived exertion (RPE). The scale ranges from 6 to 20 and matches heart rates from 60–200 beats/min. A new category begins at every second number. Borg (1990) claims that his General Scale is a category scale with ratio properties that could yield ratios, levels, and allow comparisons but still retain the same high correlation with heart rate as the 1960 scale. Table 13–D shows Borg's General scale.

The instructions for the use of the scale are as follows (modified from Borg's publications): While the subject looks at the rating scale, the experimenter says, "I will not ask you to specify the feeling, but do select a number that most accurately corresponds to your perception of [specific symptoms]. If you don't feel anything, for example, if there is no [symptom], you answer zero—nothing at all. If you start feeling something, just about noticeable, you answer 0.5—extremely weak, just noticeable. If you have an extremely strong feeling of [symptom], you answer 10—extremely strong, almost maximal. This would be the absolute strongest you have ever experienced. The more you feel—the stronger the feeling—the higher the number that you choose. Keep in mind that there are no wrong numbers; be honest, and do not overestimate or underestimate your ratings. Do not think of any other sensation than the one I ask you about. Do you have any questions?"

Let the subject get well acquainted with the rating scale before the test. During the test, let the subject do the ratings toward the end of every work period, i.e., about 30 seconds before stopping or changing the workload. If the test must be stopped before the scheduled end of the work period, let the subject rate the feeling at the moment of stoppage.

Work/Rest Cycles

If a task demands more of the worker than can be sustained, rest pauses must be taken. A general principle governing the schedule of work/rest cycles is to break up excessively heavy

Table 13–D. ***Borg's "General" RPE Scale (Ratings of Perceived Exertion CR-10)***

The Borg General Scale (1980)
0—nothing at all
0.5—extremely weak (just noticeable)
1—very weak
2—weak (light)
3—moderate
4—somewhat strong
5—strong (heavy)
6
7—very strong
8
9
10—extremely strong (almost maximal)
11 or higher–the individual's maximum

(The terms "weak" and "strong" may be replaced by "light" and "hard," respectively).

work into bouts of work that are as short as is practical for the task at hand. Frequent short rest periods reduce cumulative fatigue better than a few long breaks. The worst procedure is to let the worker go home early, exhausted.

A formula has been used to estimate the percentage of time that should be allotted to rest:

$$T_{rest}\,(\%) = \frac{M_{max} - M}{M_{rest} - M} 100 \qquad (7)$$

In the formula, T_{rest} is the percentage of rest time; M_{max} is the upper limit of the metabolic cost for sustained work; M is the metabolic cost of the task; and M_{rest} represents the resting (sitting) metabolism.

For example, suppose that M_{max} equals 350 kcal/h; and that an average value for M_{rest} is 100 kcal/h. Then assume that the task requires 525 kcal/h, which is obviously too high. Apply these values to the formula as follows:

$$T_{rest}\,(\%) = \frac{350 - 525}{100 - 525}\,100 = \frac{-175}{-425}\,100 = 41\% \qquad (8)$$

Thus, for this kind of work, rest pauses should be scheduled to last a total of 41 percent (24 min) of the hour.

As an alternative to the idle-rest pause, one may consider intermingling a light task with the heavy task. To calculate the proportion of time that should be allocated to the two tasks, consider a heavy task that requires 500 kcal/h, interrupted by a light task that requires 250 kcal/h. Again, assume that M_{max} equals 350 kcal/h.

$$T_{light\ task}\,(\%) = \frac{350 - 500}{250 - 500}\,100 = \frac{-150}{-250}\,100 = 60\% \qquad (9)$$

Accordingly, the hard work could consume 40 percent of the time, the light task 60 percent. The light, secondary work task thus actually constitutes rest time from the heavy, primary task. Sharpening tools or walking to get material or cleaning the work place can provide productive respites from heavy work.

Fatigue

If the energetic work demands exceed about half the person's maximal oxygen uptake, anaerobic energy-yielding metabolic processes play increasing roles. Anaerobic metabolism results in accumulations of potassium and lactic acid, believed to be the primary reasons for muscle fatigue, that forces the muscle to stop working. The length of time during which a person endures anaerobic work depends on the person's motivation and will to overcome the feeling of fatigue. The sense of fatigue usually coincides with the depletion of glycogen deposits in the working muscles, a drop in blood glucose, and an increase in blood lactate. However, the processes involved are not fully understood, and highly motivated subjects may maintain work that requires very high oxygen uptake for many minutes, while others feel that they must stop after just a brief effort.

Fatigue is operationally defined as a reduced muscular ability to continue an existing effort. The phenomenon of fatigue is best researched in regard to maintained static (isometric) muscle contraction. If the effort exceeds about 15 percent of a maximal voluntary contraction (MVC), blood flow through the muscle is reduced—even cut off in a maximal effort—in spite of a reflex increase in systolic blood pressure. Insufficient blood flow brings about an accumulation of potassium ions and depletion of extracellular sodium in the extracellular fluid. Combined with an intracellular accumulation of phosphate (from the degradation of ATP), these biochemical events perturb the coupling between nervous excitation and muscle-fiber contraction. This uncoupling of CNS control and muscle action signals the onset of fatigue. The depletion of ATP or creatine phosphate as energy carriers, or the accumulation of lactate, once believed the reasons for fatigue, also occur also but are not the primary reasons. Also, the increase in the number of positive hydrogen ions resulting from anaerobic metabolism causes a drop in intramuscular pH, which then inhibits enzymatic reactions, notably those in the breakdown of ATP (Kahn & Monod 1989).

When severe exercise brings about a continuously growing oxygen deficit and an increase in lactate content in the blood because of anaerobic metabolic processes, a balance between demand and supply cannot be achieved; no steady state exists, and the work requirements exceed capacity levels. The resulting fatigue can be counteracted by the insertion of rest periods. Given the same ratio of "total resting time" to "total working time," many short rest periods have more recovery value than a few long rest periods.

Avoiding fatigue:

- ➢ Allows short bursts of dynamic work and avoids long periods of static effort.
- ➢ Keeps energetic work and muscle demands low.
- ➢ Encourages taking many short rest pauses; this is better than taking a few long breaks.

The subjective sensation of fatigue is feeling tired. When tired, a person has reduced capability and desire for either physical or mental work, and feels heavy and sluggish. The sensation of fatigue has a protective function similar to hunger and thirst. Feeling fatigued forces one to avoid further stress and allows recovery to take place.

Subjective feelings of lowered motivation and deteriorated mental and physical activities may result from fatigue. Fatigue may occur together with monotony, a sensation associated with the lack of stimuli. Fatigue-induced low performance can be completely restored to its full level by rest.

The most important factors that produce fatigue are: physical work intensity (static and dynamic work); illness, pain, lack of rest (sleep), and poor eating habits; and psychological factors—worry, conflict, and possibly monotony. Hence, many different sources can be responsible for the sensation and the state of fatigue, which may be the result of an accumulation of effects stemming from various sources.

ENGINEERING ANTHROPOMETRY

Anthropometry literally means "measuring the human," traditionally in metric units, of heights, breadths, depths, and distances—all straight-line, point-to-point measurements between landmarks on the body and/or reference surfaces. Also, curvatures and circumferences following contours are measured, as is weight.

For the measurement, the body is placed in one of two defined postures with body segments at 180 degrees or 90 degrees with respect to each other. In one standard posture, the subject is required to stand erect; heels together, buttocks, shoulder blades, and back of head touching the wall; arms vertical (or extended straight forward), fingers straight. This is similar to the so-called anatomical position. The second standard posture is employed when measurements are taken on a seated subject. The (flat and horizontal) surfaces of seat and foot support are so arranged that the thighs are horizontal, the lower legs are vertical, and the feet are flat on their support. The subject is nude, or nearly so, and unshod. Figure 13–8 shows reference planes and descriptive terms often used in anthropometry. Figures 13–9 and 13–10 show important anatomical landmarks of the human body. The NASA-Webb *Anthropometric Sourcebook* (1978) contains much information on measurement techniques in general and on military anthropometric data in particular. More recent publications by Gordon, Churchill, Clauser et al (1989), Kroemer, Kroemer, and Kroemer-Elbert (1997, 2001), Lohman, Roche, and Martorel (1988), and Roebuck (1995) condense and update this information.

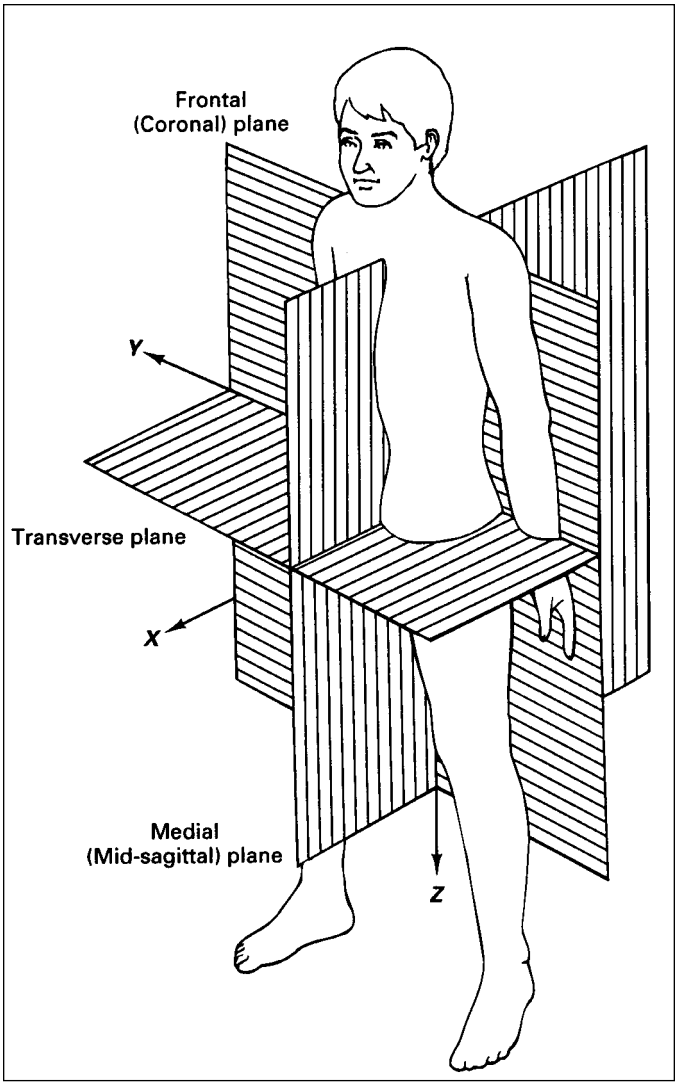

Figure 13–8. Measuring planes and terms used in anthropometry. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency.* Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

The existing anthropometric information has been gathered while the subjects assume highly stylized and standardized postures.These postures are quite different from the body positions assumed while working, particularly when the worker is moving around. Hence, the ergonomic designer for practical applications must interpret current data.

Body-build typologies (somatotypes), such as those developed by Kretschmer, Sheldon, or Heath-Carter, have neither proven to be suitable for engineering anthropometry, nor are they reliable predictors of attitudes, physical capabilities, or limitations relative to performance in industrial systems. Hence, somatotyping is of little or no value for engineers or managers.

Civilian Body Dimensions

The anthropometric literature abounds with data on military personnel. No large and reliable surveys of the complete U.S.

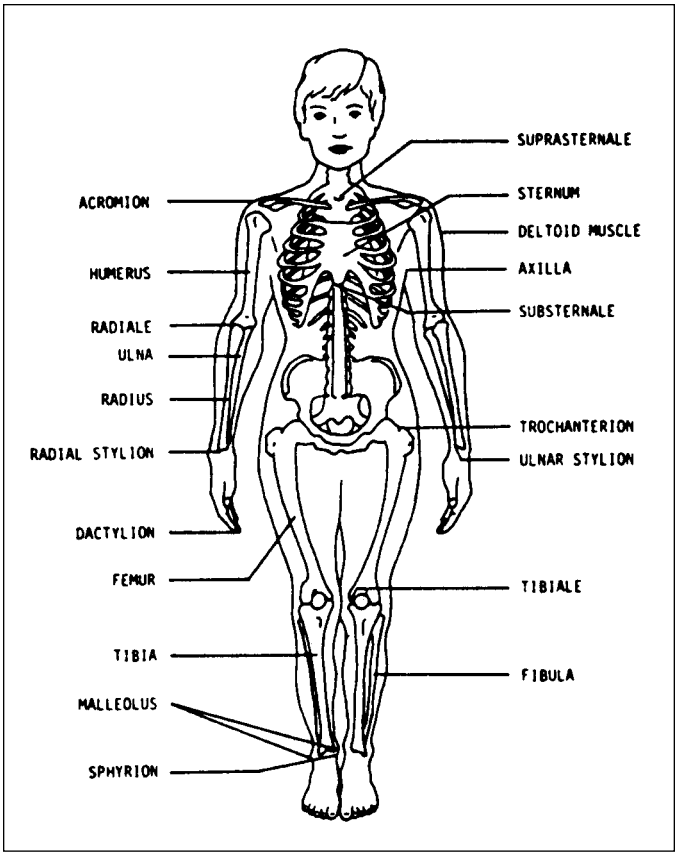

Figure 13–9. Landmarks on the human body in the frontal view.

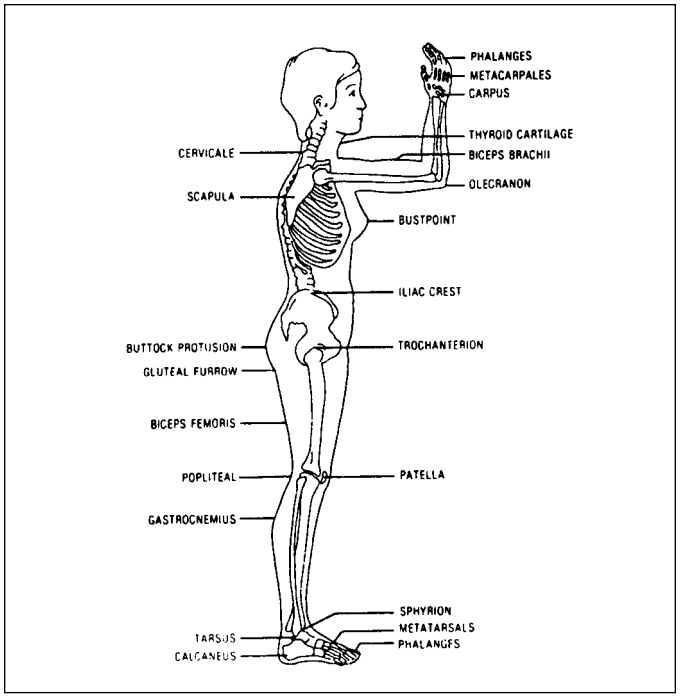

Figure 13–10. Landmarks on the human body in the lateral view.

civilian population have been performed during recent decades. Hence, anthropometric data applied describing the body sizes of the civilian population are taken from those of soldiers who are generally young and healthy. Head, hand, and foot dimensions are the same for soldiers and civilians; and the other body dimensions measured in the (latest) 1988 survey of the U.S. Army (Gordon, Churchill, Clauser et al, 1989) compare well with the few data available on the working population (Marras & Kim, 1993). Yet body weight is distinctly different between soldiers and civilians; civilians have more extreme values. An up-to-date compilation of estimated civilian body dimensions is presented in Table 13–E. This table shows the 5th, 50th, and 95th percentile dimensions as well as the standard deviations. Assuming a normal distribution of the data, the 50th percentile coincides with the mean (average) value.

Anthropometric Statistics

Fortunately, anthropometric data are usually dispersed in a reasonably normal (Gaussian) distribution (with the occasional exception, especially of muscle strength data). Hence, regular parametric statistics apply in most cases. The data cluster in the center of the set at the 50th percentile, which coincides with the mean m (the average). The peakedness or flatness of the data cluster is measured by the standard deviation. The commonly used formulae to calculate the most often needed statistical descriptors of normal distributions follow.

A normally distributed set of n data is described by two simple statistics:

The *50th percentile* is by definition the same as the mean m (also commonly called average):

$$m = \sum x/n \tag{10}$$

where $\sum x$ is the sum of the individual measurements.

The *Standard Deviation (SD)* describes the distribution of the data:

$$SD = [\sum (x-m)^2/n-1]^{1/2} \tag{11}$$

It is often useful to describe the variability of a sample by dividing the standard deviation SD by the mean m. The resulting

Coefficient of Variation (CV) (in percent) is:

$$CV = 100\ SD\ /\ m \tag{12}$$

A percentile value p of a normal distribution is calculated by multiplying the standard deviation SD by a factor k, selected from Table 13–F. Then subtract the product from the mean m if p is below the mean:

$$p = m - k\ SD \tag{13}$$

Table 13–E. *Anthropometric Measured Data in mm of U.S. Adults, 19 to 60 years of age*

	Men				Women			
	5th		95th		5th		95th	
Dimension	Percentile	Mean	Percentile	SD	Percentile	Mean	Percentile	SD
Heights, Standing								
1. Stature [99]	1647	1756	1867	67	1528	1629	1737	64
2. Eye height, standing [D19]	1528	1634	1743	66	1415	1516	1621	63
3. Shoulder height (acromion), standing [2]	1342	1443	1546	62	1241	1334	1432	58
4. Elbow height, standing [D16]	995	1073	1153	48	926	998	1074	45
5. Hip height (trochanter) [107]	853	928	1009	48	789	862	938	45
6. Knuckle height, standing	na	na	na	na	na	na	na	na
7. Fingertip height, standing [D13]	591	653	716	40	551	610	670	36
Heights, Sitting								
8. Sitting height [93]	855	914	972	36	795	852	910	35
9. Sitting eye height [49]	735	792	848	34	685	739	794	33
10. Sitting shoulder height (acromion) [3]	549	598	646	30	509	556	604	29
11. Sitting elbow height [48]	184	231	274	27	176	221	264	27
12. Sitting thigh height (clearance) [104]	149	168	190	13	140	160	180	12
13. Sitting knee height [73]	514	559	606	28	474	515	560	26
14. Sitting popliteal height [86]	395	434	476	25	351	389	429	24
Lengths, Reaches								
15. Shoulder-elbow length [91]	340	369	399	18	308	336	365	17
16. Elbow-fingertip length [54]	448	484	524	23	406	443	483	23
17. Overhead grip reach, sitting [D45]	1221	1310	1401	55	1127	1212	1296	51
18. Overhead grip reach, standing [D42]	1958	2107	2260	92	1808	1947	2094	87
19. Forward grip reach [D21]	693	751	813	37	632	686	744	34
20. Arm length, vertical [D3]	729	790	856	39	662	724	788	38
21. Downward grip reach [D43]	612	666	722	33	557	700	664	33
Depths								
22. Chest depth [36]	210	243	280	22	209	239	279	21
23. Abdominal depth, sitting [1]	199	236	291	28	185	219	271	26
24. Buttock-knee depth, sitting [26]	569	616	667	30	542	589	640	30
25. Buttock-popliteal depth, sitting [27]	458	500	546	27	440	482	528	27
Breadths								
26. Shoulder breadth (bicrominal) [10]	367	397	426	18	333	363	391	17
27. Shoulder breadth (bideltoid) [12]	450	492	535	26	397	433	472	23
28. Hip breadth, sitting [66]	329	367	412	25	343	385	432	27
29. Span [98]	1693	1823	1960	82	1542	1672	1809	81
Head, Hand, and Foot Dimensions								
30. Head length [62]	185	197	209	7	176	187	198	6
31. Head breadth [60]	143	152	161	5	137	144	153	5
32. Hand length [59]	179	194	211	10	165	181	197	10
33. Hand breadth [57]	84	90	98	4	73	79	86	4
34. Foot length [51]	249	270	292	13	224	244	265	12
35. Foot breadth [50]	92	101	110	5	82	90	98	5
36. *Weight* (kg), estimated by Kroemer	58	78	99	13	39	62	85	14

Excerpted from Gordon, Churchill, Clauser, et al (1989) and Greiner (1991), who used the numbers in brackets. These are measured, not estimated, data that may be slightly different from values calculated from Mean plus or minus 1.65 Standard Deviation—see Table 13–F.

If p is above the average add the product to the mean m:

$$p = m + k\,SD \tag{14}$$

A new mean from the sum of two distributions is simply the sum z of the means of the x and y:

$$m_z = m_x + m_y \tag{15}$$

The standard deviation of the summed distribution z is

$$SD_z = [SD_x^2 + SD_y 2 + 2\,r\,SD_x\,SD_y\,]^{1/2} \tag{16}$$

The mean of the difference between two distributions is

$$m_z = m_x - m_y \tag{17}$$

The standard deviation of the new distribution is

$$SD_z = [SD_x^2 + SD_y^2 - 2\,r\,SD_x\,SD_y\,]^{1/2} \tag{18}$$

Equations 16 and 18 contain (Pearson's) correlation coefficient r. It describes the relationship between two sets of data. The value of r ranges from +1 (a "perfect" positive correlation; as x increases, y increases as well) over 0 (no correlation at all between x and y) to –1 (also perfect, but negatively so: as x increases, y decreases).

Determining Percentiles

Anthropometric data often are best presented in percentiles. They provide a convenient means of describing the range of body dimensions to be accommodated, making it easy to locate the percentile equivalent of a measured body dimension. Also, the use of percentiles avoids the misuse of the average in design (as is discussed later). There are two ways to determine given percentile values p.

One is to calculate values of p, as described above. The other is to simply graph the data distribution and find the critical percentile values from the curve by measuring, counting, or estimating. This technique works well whether the distribution is normal, skewed, binomial, or in any other form.

The following examples for calculating p-values are selected and adapted from those used by Kroemer, Kroemer and Kroemer-Elbert (2001).

ARM LENGTH

The Task: Calculate the 95p shoulder-to-fingertip length.

The Solution: You know that the mean lower arm (LA) link length (with the hand) is 442.9 mm with a standard deviation of 23.4 mm. The mean upper arm (UA) link length is 335.8 mm and its standard deviation is 17.4 mm.

The multiplication factor of k = 1.65 (from Table 13–F) leads to the 95th percentile. But simply adding the two 95p lengths would be a mistake because that would disregard their correlation; instead, establish the sum of the mean values first, using Equation 15:

$$m_A = m_{LA} + m_{UA} = 442.9 + 335.8 = 778.7 \text{ mm}$$

Then compute the standard deviation for m_A from Equation 16 with an assumed correlation coefficient of 0.4:

$$SD_A = [23.4^2 + 17.4^2 + 2\,(0.4)\,(23.4)\,(17.4)]^{1/2} \text{ mm} = 34.3 \text{ mm}$$

Finally, the 95p total arm length can be calculated via Equation 14:

$$A_{95} = 778.7 \text{ mm} + 1.65\,(34.3 \text{ mm}) = 835.3 \text{ mm}$$

Table 13–F. *Calculation of Percentiles*

Percentile p		Central Percentage	
$x_i = \bar{x} - kS$ (below mean)	$x_j = \bar{x} + kS$ (above mean)	Included in the Range x_{pi} to x_{pj}	k
0.5	99.5	99	2.576
1	99	98	2.326
2	98	96	2.06
2.5	97.5	95	1.96
3	97	94	1.88
5	95	90	1.65
10	90	80	1.28
15	85	70	1.04
16.5	83.5	67	1.00
20	80	60	0.84
25	75	50	0.67
37.5	62.5	25	0.32
50	50	0	0

KEYBOARD HEIGHT ABOVE THE SEAT

The Task: Establish the surface height of a keyboard so that the sitting operator has the forearms and wrists horizontal.

The Solution: Assume that having the tops of the keys at elbow height will allow the operator to keep the wrists straight and the forearms horizontal while the upper arms hang vertically from the shoulder joints. It appears appropriate to adjust the key height in a range that lowest is proper for the 10th percentile female elbow clearance and highest fits the 90th male clearance.

The elbow height above the seat pan is listed for Americans in Table 13–E: females have a mean of 220.5 mm with a SD of 26.8 mm; the corresponding numbers for males are 230.6 mm and 27.2 mm.

To use Equation 14 above, take k = 1.28 from Table 13–F as the multiplication factor for determining the 10th and 90th percentiles. The calculations show 10p values of 186 mm for females and 196 mm for males; the 90p values are 265 mm for males and 255 mm for females.

Consequently, under the assumptions made, the height of the key tops should be adjustable from about 19 to 27 cm above the seat pan level.

Percentiles serve the designer in several ways. First, they establish the portion of a user population that will be included in (or excluded from) a specific design solution. For example: a certain product may need to fit everybody who is taller than the 25th percentile or smaller than the 95th percentile in a specified dimension, such as grip size or arm reach. Thus, the 25 percent having values smaller than 25th percentile and the five percent having values larger than 95th percentile will not be fitted while 70 percent of all users will be accommodated.

Second, percentiles are easily used to select subjects for fit tests. For example: if a product needs to be tested, persons with 25- or 95-percentile values in the critical dimensions can be employed for use tests.

Third, any body dimension, design value, or score of a subject can be located exactly. For instance: a certain foot length can be described as a given percentile value of that dimension, a certain seat height can be described as fitting a certain percentile value of *popliteal height* (a measure of lower leg length), or a test score can be described as being a certain percentile value.

Fourth, the use of percentiles helps in the selection of persons who can use a given product. For example: if the cockpit of an airplane is designed to fit 5th to 95th percentiles, one can select cockpit crews whose body measures are between those percentiles in the critical design dimensions.

The Phantom of the Average Person

Several simple—but false—ideas about the proportions of the human body have been used in the past. They assumed that all body dimensions, such as lengths, breadths, and circumferences, can be represented as given fixed proportions (percentages) of one body dimension—most often, stature. Obviously, such a simplistic assumption contradicts reality: The relationships among body dimensions are neither necessarily linear nor the same for all persons. In spite of the obvious fallacy of the model, *single-percentile constructs* have been generated. These assume that persons exist whose body segments are all of the same percentile value. Not only the 50th-percentile phantom (the average person) was used as a design template, but other ghostly figures were created that have, for example, all 5th- or 95th-percentile values. Of course, designs for these figments do not fit actual users.

Designing to Fit the Human Body

It is not suitable to design for the average person phantom because no one is average in many or all body dimensions. The correct design approach is to select the specific anthropometric dimension(s) to be fitted and to establish (for each dimension) the design range (such as from the 5th to the 95th percentile) so that proper fit will be achieved.

"MIN-MAX STRATEGY" FOR FITTING SMALL AND LARGE PERSONS

Instead of the thoughtless and useless average-person concept, the *min-max strategy* is often successfully applied when workstations, tools, and tasks must be designed to fit small and large operators, as well as everybody in-between. The minimal dimensions are derived from the smallest operators' needs to see, to reach, or to apply force; yet these dimensions may not accommodate large persons who can reach farther, can see higher, and need more open space for their bodies. These larger individuals' dimensions establish the *maximal* boundaries. One good solution, if feasible, is to have workplaces and tools and other work objects in different sizes between minima and maxima; another other good solution is to have *adjustable* dimensions. *Adjustability* allows good fit, but is often expensive; therefore, one often attempts to design just one workstation that suits all workers, or at least most of them. This requires that the designer first decides what the important minimal and maximal values are that will be accommodated (for example, in body size, reach, or strength).

See the Bibliography for references by Eastman Kodak Company (1983, 1986), Kroemer et al (1997, 2001), and Roebuck (1995), which guide readers on ergonomic designs to fit the body.

Population Changes

Since World War I, increases in certain body dimensions have been observed. Many children grow to be taller than their parents. This increase in stature has been in the range of about 1 cm per decade, but now seems to be leveling off. Another even more conspicuous increase has occurred in body weight, with increments of 2 to 3 kg per decade.That gain is still going on, in spite of public emphasis on proper nutrition and exercise.

Altogether, such secular developments of body dimensions are rather small and slow (except for weight). Hence, for most engineers, the changes in body data should have little practical consequences for the design of tools, equipment, workstations, or work clothes, since virtually none are designed for use over many decades. However, one may have to consider increased ranges of variability in certain dimensions—and this is best expressed by percentile values.

The working population in North America has been changing in gender, occupation, age, and composition. Today, the general work force has many more women in occupations that were dominated by men just a few decades ago. Occupations have changed drastically; computers and service industries are pulling people from traditional blue-collar work. Average life expectancy has increased in the United States since 1900 by 27 years to nearly 80 years.

Design for special population subgroups does require the consideration of other-than-normal ranges of body sizes. These groups of people include pregnant women and the elderly (Annis et al, 1991; Annis & McConville, 1996; and Kroemer et al, 2001). Approximately one of five North Americans is 65 years and older; thus, the number of elderly

workers in the U.S. work force is expected to increase within the very near future.

Another population subgroup is a result of immigration, for example, Central and South Americans, who may be relatively short in stature. This can have a conspicuous effect on the anthropometry of the working population in certain regions. Hence, the anthropometric data that describe local workers on the shop floor, in the office, or users and operators of equipment can be quite different from national statistics.

BIOMECHANICS

Biomechanics explains characteristics of the human body in mechanical terms. More than 300 years ago, Giovanni Alfonso Borelli described a model of the human body that consisted of links (bones) joined in their articulations and powered by muscles bridging the joints. This *stick person*, refined and embellished with mass properties and material characteristics, still underlies most current biomechanical models of the human body. More than 100 years ago, Harless determined the masses of body segments; Braune and Fischer investigated the interactions between mass distribution, body posture, and external forces applied to the body; and von Meyer discussed the body's statics and mechanics. Biomechanical research has investigated responses of the body to vibrations and impacts, functions and strain properties of the spinal column, and human motion and strength characteristics. (See Chaffin et al, 1999, or Kroemer et al, 2001, for more information.)

When treating the human body as a mechanical system, many gross simplifications are necessary, and many functions, such as mental processes, may be disregarded. However, within its limitations and simplifications, a large body of useful biomechanical information is already available, and this scientific and engineering field is developing rapidly. (See Chaffin et al, 1999; Kroemer et al, 1997, 2001; Nordin et al, 1997; Oezkaya & Nordin, 1991.)

Body Strength

Assessment of human muscle strength is a biomechanical procedure. This assessment uses Newton's Second and Third Laws, which state that force is proportional to mass times acceleration, and that each action is opposed by an equivalent reaction. Since human muscle strength currently is not measurable at the muscle in vivo and in situ, human strength is described by the amount of force or torque applied to an external measuring instrument—which is the kind of data that the engineer needs to design tools and equipment.

Inside the body, muscular force vectors develop torque (also called moment) around the body joint bridged by the muscle. *Torque* is the product of force and its lever arm to the body joint; with the direction of the force perpendicular to its lever arm. In kinesiology, the lever arm is often called the mechanical advantage.

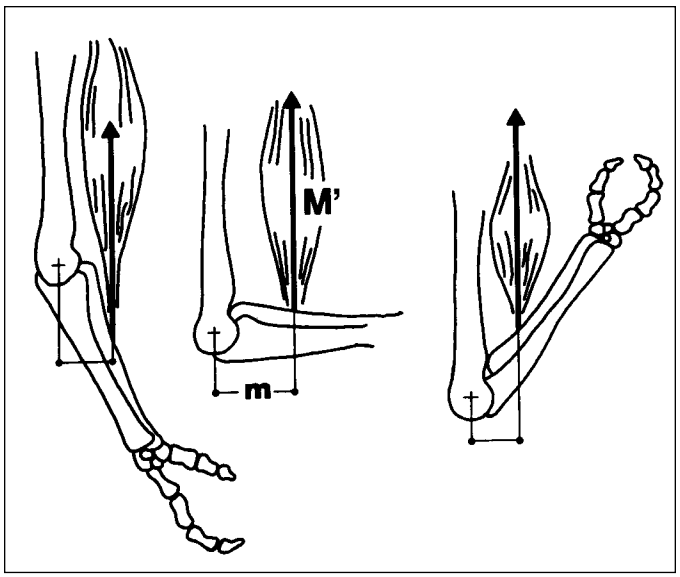

Figure 13–11. Changing lever arm (m) of the muscle force (M) with varying elbow angle.

Figure 13–11 uses the example of elbow flexion to illustrate these relationships. The primary flexing muscle (biceps brachii) exerts a force (M) at the forearm at its lever arm (m) about the elbow joint. This generates a torque: $T=mM$. Since, by torque definition, a right angle must exist between lever arm and force vector, the useful lever arm is smaller when the elbow angle is wide open, or acute, than when the elbow angle is a right angle.

The correct unit to express force is the newton (N) while torque (moment) is measured in newton-meter (Nm). A 1-lb force is approximately 4.45 N, and 1-kg force (kgf) equals 9.81 N. The pound, ounce, and gram are not force but mass units. According to Newton's Second Law, force equals mass times acceleration; hence, weight (of a mass) generates a force proportional to gravitational acceleration. Force (as well as torque) has vector qualities, which means that it must be described not only in terms of magnitude, but also by direction, by the line of force application, and the point of its application.

Figure 13–12 shows a more realistic model of the muscle forces that flex or extend the forearm about the elbow joint. It indicates an external force, E, and hand/forearm weight, W, at their respective lever arms, e and w. It also shows the force vectors of the two major flexor muscles, the biceps, B, and the radiobrachialis, R, acting at their specific lever arms, b and r, about the elbow. Also shown is the force vector of the triceps, T, with its lever arm, t. With a change in elbow angle, α, all force vectors change their angles of application, τ, ρ, β, and ε.

For static equilbrium, all forces and all torques must sum to zero. This provides three equilbrium equations, one each for the horizontal forces, the vertical forces, and the moments about the elbow joint. Including the joint reactions, indicated by H for horizontal and V for vertical force, and M for moment, these equations are as follows:

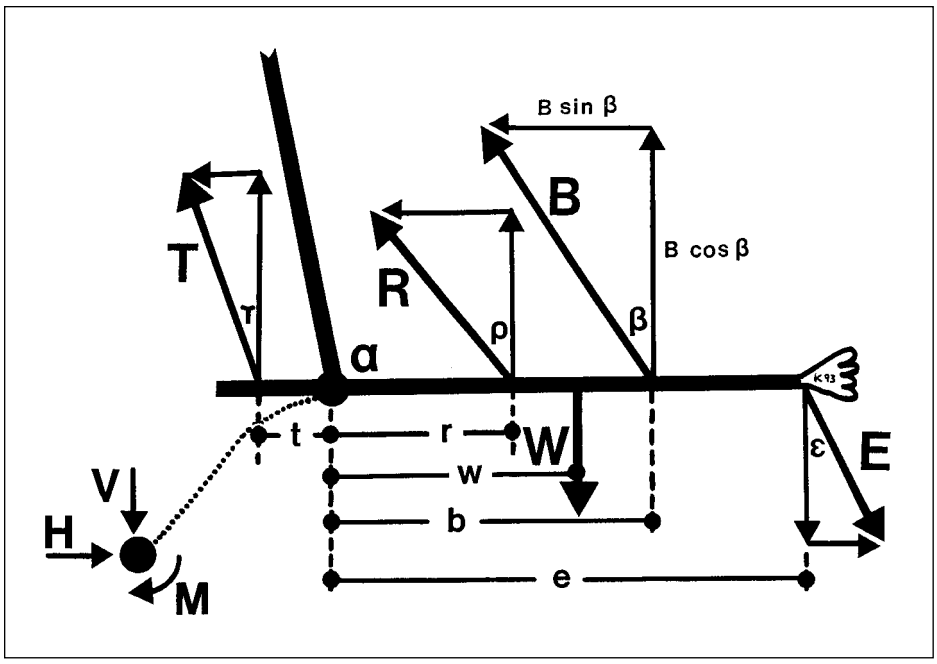

Figure 13–12. A more sophisticated biomechanical model of elbow flexion with indications of force vectors, vector directions, and lever arms.

➢ (Horizontal Forces) = 0
➢ $= T \sin\tau + R \sin \rho + B \sin \beta - E \sin \varepsilon - H$ (19)

➢ (Vertical Forces) = 0
➢ $= T \cos \tau + R \cos \rho + B \cos \beta - E \cos \varepsilon - W - V$ (20)

➢ (Moments About Joint) = 0
$= tT \cos \tau - rR \cos \rho - bB \cos \beta + eE \cos \varepsilon + wW - M$ (21)

These equations can be solved only if there are no more unknowns than equations. One can determine the length of the lever arms from anatomy. The angles are measured or taken from anatomy and geometry. The weight of the forearm can be calculated from geometry or taken from biometric tables (see, for example Chaffin et al, 1999, or Kroemer et al, 1997). The external force can be measured. Still, this leaves the muscular force vectors (*T*, *R*, *B*) unknown, as well as the joint reaction forces (*H* and *V*), and the joint reaction moment (*M*). Various possibilities exist to reduce that number of unknowns to three, ie, the same as the number of equations. These approaches include assumption of no coactivation, or of certain coactivation ratios (e.g., according the cross-sections of the muscles) or according to electromyographic (EMG) signals. Other techniques rely on statistical optimization procedures (Karwowski & Marras 1999; Salvendy 1997).

When movement occurs the biomechanical conditions become more complex than those just described for the static case. In dynamics, additional forces must be considered as body segments rotate about their proximal joints. This introduces tangential, centrifugal, and Coriolis forces, which may also generate new torques, as does the inertia of the segment and possibly of an external load.

The principles of vector algebra can be applied to a chain of body segments; for example, pushing or lifting with the hands transmits torques (forces) from the wrist to the elbow joint, to the shoulder, down the spinal column, and across hip, knee, and ankle joints to the ground where the torques (forces) are generated that counteract the hand effort. Such kinematic chain models are used to assess the weakest links of the human body. These are often in the spinal column where especially low-back injuries are frequent.

Measuring Body Strength

Voluntary muscle strength moves the segments of the body and generates energy exerted on outside objects when one performs work. There are more than 200 skeletal muscles in the body. They consist of bundles of muscle fibers: each is wrapped—as is the total muscle—in connective tissue in which nerves and blood vessels are embedded. At the ends of the muscle, the tissues combine to form tendons that connect the muscle to bones.

The only active action a muscle can take is to contract; elongation is brought about by force external to the muscle. Contraction actually occurs in fine structures of the muscle, called filaments, that slide along each other. The nervous control for muscular contraction is provided by the neuromuscular system, which carries signals from the brain forward to the muscle and also provides feedback. Electrical events associated with contraction of motor units of the muscle are observable in an electromyogram.

Model of Strength Generation

Figure 13–13 shows a simple model of the generation of muscular strength. Activation signals *E* travel from the central nervous system (CNS) along the efferent pathways to the muscle. Here, they generate contraction, which, modified by the existing physical conditions, generates the strength that is applied to a measuring instrument (or a work piece or

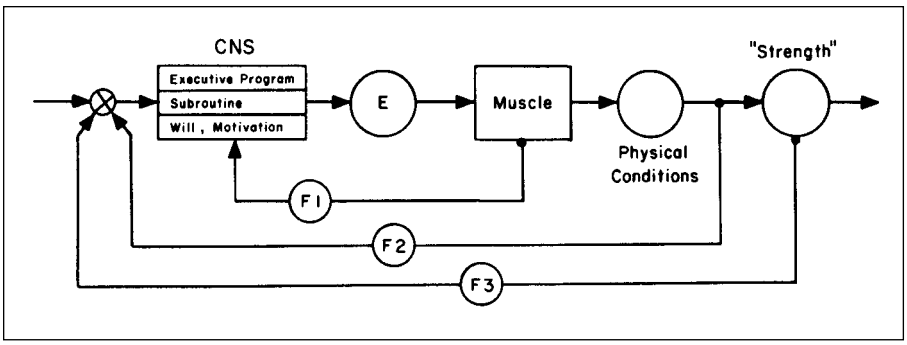

Figure 13–13. Model of generation and control of muscle strength exertion. (Reprinted with permission from Kroemer, Kroemer, and Kroemer-Elbert, 2001.)

hand tool). Three feedback loops are shown—the first one indicates reflexes; the second, transmitted sensations of touch, pressure, and kinesthetic signals; the third, sound and vision events related to the strength exerted.

Consider the feed-forward section of the model. Currently there is no suitable means to measure the executive program or the subroutines in the CNS, or the effects of will or motivation, on the motor signals generated. The efferent excitation impulses travel along the efferent nerves to the muscles where they generate contraction signals. These signals can be observed in an EMG, which, however, is difficult to interpret especially under dynamic conditions. Although it would be very useful to directly measure the tension within muscles in situ, at the time of this writing, there are no instruments available that can do so. It is difficult to record and control the mechanical conditions within the body (i.e., the lever arms of the tendon attachments or the pull angles of muscles with respect to the bones to which they are attached), but the mechanical conditions outside the body can be observed and controlled. This concerns the kind and location of the coupling between the body and the device; the direction of exerted force or torque; the time history of this exertion; the position and support of the body; and environmental conditions, such as temperature and humidity.

Hence, with current means, only the output of this complex system, called muscle strength, can be defined and measured. Since strength has vector qualities and is time-dependent, it must be recorded not only in magnitude, but also in direction, point of application, and time history.

Measuring Techniques

According to Newton's Second Law (force equals mass times acceleration, or torque equals moment of inertia times rotational acceleration), the measurer first has to decide whether or not acceleration shall be present.

If there is no acceleration, there will be no change in speed. If speed is set to zero, then adjacent body segments will not move with respect to each other. Hence, the length of the muscle(s) spanning the joint remains constant. Physically, this means that the measurement of muscle strength is performed in the static condition. Biologically, this condition is called isometric, meaning constant muscle length. Thus, in this case, the terms *static* and *isometric* are factually synonymous. Measurement of static strength is straightforward and involves only simple instrumentation; and almost all current information on muscle strength reflects data on isometric exertions.

If velocity is not zero but is constant, the condition is called *isokinematic*, meaning constant motion. Measurement devices that establish a constant angular velocity around a given body articulation are commercially available. During their constant-speed phase (but neither at the beginning nor at the end of the motion), these devices provide a defined condition for which the exerted strength can be recorded. Only the angular velocity is controlled, while the amount of strength actually exerted at any moment remains under control of the subject. (Hence, the devices are not isokinetic even if falsely labeled so.)

During acceleration (the velocity is not constant but variable), strength is exerted under dynamic conditions that need to be defined and controlled depending on the circumstances selected. Such experimental control is possible in the laboratory, but likely to be very difficult and often impractical. Extreme cases of dynamic conditions are feats of strength at sports events, which can neither be easily measured nor controlled since they are highly specific to the situation and the person. Table 13–G presents an overview of classifications of strength exertions and their experimental control and measurement.

One technique commonly used to control dynamic conditions is to have the subject work isoinertially, that is, move constant masses (weights). To assess lifting capability, the weight is usually increased from test to test until one can determine the largest mass that the subject can lift (see the section on material handling later in this chapter).

THE STRENGTH TEST PROTOCOL

After choosing the type of strength test to be done and the appropriate measurement technique, an experimental protocol must be devised. This includes the protection of the subjects and of the information obtained from them; the control of the experimental conditions; the use, calibration, and maintenance of the measurement devices; and (usually) the avoidance of training and fatigue effects.

When selecting subjects, take care to ensure that they are a representative sample of the population about which data are to be gathered. When managing experimental condi-

Table 13–G. ***Dependent and Independent Variables in the Measurement of Muscle Strength***

	Isometric (Static)		*Isovelocity (Dynamic)*		*Isoacceleration (Dynamic)*		*Isojerk (Dynamic)*		*Isoforce (Static or Dynamic)*		*Isoinertia (Static or Dynamic)*		*Free Dynamic*	
Variables	**Indep.**	**Dep.**	**Indep.**	**Dep.**	**Indep.**	**Dep.**	**Indep.**	**Dep.**	**Indep.**	**Dep.**	**Indep.**	**Dep.**	**Indep.**	**Dep.**
Displacement, linear/angular	constant* (zero)		C or X		C or X		C or X		C or X		C or X			X
Velocity, linear/angular	0		constant		C or X		C or X		C or X		C or X			X
Acceleration, linear/angular	0		0		constant		C or X		C or X		C or X			X
Jerk, linear/angular	0		0		0		constant		C or X		C or X			X
Force, torque	C or X		C or X		C or X		C or X		constant		C or X			X
Mass, moment of inertia	C		C		C		C		C		constant		C or X	
Repetition	C or X		C or X		C or X		C or X		C or X		C or X		C or X	

Indep = independent
Dep = dependent
C = variable can be controlled
* = set to zero
0 = variable is not present (zero)
X = can be dependent variable
The boxed constant variable provides the descriptive name.
(Adapted from Kroemer, Marras, McGlothlin, et al., 1990.)

tions, control of motivational aspects is particularly difficult. It is widely accepted (outside sports and medical function testing) that the experimenter should not give exhortations and encouragements to the subject. The so-called "Caldwell regimen" (Caldwell et al, 1974) pertains to isometric strength testing, but can be adapted for a dynamic test. The following is an edited excerpt of this regimen.

Definition: "Static body strength is the capacity to produce torque or force by a maximal voluntary isometric muscular exertion. Strength has vector qualities and therefore should be described by magnitude and direction."

1. Measure static strength according to the following conditions: (a) Static strength is assessed during a steady exertion sustained for four seconds. (b) The transient periods of about one second each, before and after the steady exertion, are disregarded. (c) The strength datum is the mean score recorded during the first three seconds of the steady exertion.

2. Treat the subject as follows: (a) The person should be informed about the purpose of the test and the involved procedures. (b) Instructions should be kept factual and not include emotional appeals. (c) The subject should be told to "increase to maximal exertion (without jerk) in about one second and then maintain this effort during a four-second count." (You may want to use a different procedure and time for special conditions, e.g., for the measurement of finger strength.) (d) During the test, the subject should be informed about his/her general performance in qualitative, non-comparative, positive terms. Do not give instantaneous feedback during the exertion. (e) Rewards, goal setting, competition, spectators, fear, noise, etc. can affect the subject's motivation and performance and therefore should be avoided.

3. Provide a minimal rest period of two minutes between related efforts; more if symptoms of fatigue are apparent.

4. Describe the conditions existing during strength testing: (a) Body parts and muscles chiefly used. (b) Body position (or movement). (c) Body support or reaction force available. (d) Coupling of the subject to the measuring device. (e) Strength measuring and recording device.

5. Describe the subjects: (a) Population and sample selection including sample size. (b) Current health: a

medical examination and a questionnaire are recommended. (c) Gender. (d) Age. (e) Anthropometry (at least height and weight). (f) Training related to the strength testing.

6. Report the experimental results: (a) Number of data collected. (b) Minimum and maximum values. (c) Median and mode. (d) Mean and standard deviation for normally distributed data points; for a non-normal distribution, lower and upper percentile values such a 1st, 5th, 10th, 25th, 75th, 90th, 95th, or 99th percentiles.

DESIGNING FOR BODY STRENGTH

The engineer or designer who wants to consider human strength has to make a number of decisions, including the following:

- Is strength use mostly static or dynamic? If it is static, information about isometric strength capabilities can be used. If it is dynamic, other additional considerations apply, concerning, for example, physical endurance (circulatory, respiratory, metabolic) capabilities of the operator, prevailing environmental conditions, etc. Physiology and ergonomic texts (e.g., Astrand & Randahl, 1986; Kroemer et al, 1997, 2000; Winter, 1990) provide such information.
- Is the exertion by hand, by foot, or with the whole body? For each of these situations, specific design information is available. If a choice is still possible, it must be based on physiological and ergonomic considerations to achieve the safest, least strenuous and most efficient performance. In comparison to hand movements over the same distance, foot motions consume more energy, and are less accurate and slower, but they are stronger.
- Is a maximal or a minimal strength exertion the critical design factor? *Maximal user output* usually determines the structural strength of the object, so that the strongest operator may not break a handle or a pedal. The design value is set, with a safety margin, above the highest perceivable strength application.
- *Minimal user output* is that exertion expected from the weakest operator, which still yields the desired result, so that a door handle or brake pedal can be successfully operated or a heavy object moved.
- The range of expected strength exertions is, obviously, that between the specified minimum and maximum. Average user strength is usually of no design value.
- Most body-segment strength data are available for static (isometric) exertions. They provide reasonable guidance also for slow motions, although they are probably a bit too high for concentric motions and too low for eccentric motions. As a general rule, strength exerted in motion is less than that measured in static positions located on the path of motion.
- Measured strength data are often treated statistically as if they were normally distributed and reported in terms of averages (means) and standard deviations. This dubious procedure is not of great practical concern, however, because usually the data points of special interest are the extremes. Often the 5th and 95th percentile values are selected. These can be determined easily, if not by calculation, then by estimation.

HANDLING LOADS: LIFTING, LOWERING, PUSHING, PULLING, CARRYING

We all handle material daily. We lift, hold, carry, push, pull, and lower while moving, packing, and storing objects. The objects may be soft or solid, bulky or small, smooth or with corners and edges; the objects may be bags, boxes, or containers that come with or without handles. We may handle material occasionally or repeatedly. We may handle material during leisure activities as part of the paid work. Manual handling involves lifting light or heavy objects. Heavy loads pose additional strain on the body owing to their weight or bulk or lack of handles. But even lightweight and small objects can strain us because we have to stretch, move, bend, or straighten out body parts, using fingers, arms, trunk, and legs.

Material handling is among the most frequent and the most severe causes of injury all over the world and in U.S. facilities. The most common injuries are strains in the low back. The direct and indirect costs are enormous, and the human suffering associated with material-handling injuries is severe.

Seven Keys of Load Handling

Kroemer identified *seven keys* (1997) as the major ergonomic tools for safe and efficient material handling:

Key 1. Facility Layout—Initial layout or improvement of facilities contributes essentially towards safe and efficient material transfer. The selection of either product or process layout and accordingly how the flow of material is organized and designed in detail, determines how people are involved and how they must handle material.

Key 2. Job Design—Job design determines the stress imposed on the worker by the work. Initially, the engineer must decide whether to assign certain tasks to a person or a machine. Furthermore, the layout of the task, the kind of material-handling motions to be performed, the organization of work and rest periods, and many other engineering and managerial techniques determine whether a job is well-designed, safe, efficient, and agreeable for the operator.

Key 3. Equipment—Selection, use, and improvement of equipment, machines, and tools, strongly affect material handling requirements. Ergonomic principles must be considered, for example, operator space requirements, control design, visibility, and color and sign coding.

Key 4. People—This key concerns people as material handlers, particularly with regard to body size, strength, and

energy capabilities. People are the kingpins in manual material activities because they supervise, control, operate, drive, and actually handle material. If people are not needed in the system, then it should be automated. If they are needed, the system must be designed for them.

Key 5. Training Material Handlers—For decades training in safe lifting procedures has been advocated and conducted. Training is expected to reduce severity and frequency of injuries, develop specific material handling skills, further awareness and responsibility for one's own safety, and improve specific physical fitness characteristics. Participants have been selected at random, or chosen according to risk, previous injuries, age, etc.; they were volunteers or they included all employees.

Many studies on training outcomes are scientifically deficient because they do not follow an experimental design that allows the assessment of reliability and validity of the results of the experimental treatment. Granted, it is difficult (because of work interference, time needed and expenses) to conduct a field experiment in which one varies only the independent variable and excludes confounding variables and uncontrollable interferences. Still, including a control group in the experimental design is often feasible, and it allows the evaluation of the claimed effect of the experimental training treatment.

Key 6. Screening Material Handlers—While training is one approach to "fit the person to the job," another is to select suitable persons, i.e., screening individuals to place on strenuous jobs those who can do them safely. This screening may be done either before employment, before placement on a new job, or during routine examinations during employment.

A basic premise of personnel selection by physical characteristics is that the risk of overexertion injury from manual material handling decreases as the handler's capability to perform such activity increases. This means that a test should be designed to allow judgment about the match between a person's capabilities for load handling, and the actual load-handling demands of the job. Hence, this matching process requires that one quantitatively knows both the job requirements and the related capabilities of the individual. (Of course, if the job requirements are excessive, they should be lowered before any matching is attempted.)

Key 7. Ergonomic Design of Workplace and Work Task—The most effective and efficient way to reduce material handling injuries is to design equipment ergonomically, so that job demands are matched to human capabilities. Designing to fit the human can take several approaches. The most radical solution is to design out manual material movement by assigning it to machines: *no people involved, no people at risk.* If people must be involved, load weight and size shall be kept small, best accompanied by ergonomic design of the work task, i.e., by selecting the proper type of material handling movements (e.g., horizontal push instead of vertical lift) and their frequency of occurrence. The location of the object with respect to the body is very important: best between hip and shoulder height, directly in front of the body so as to avoid twisting or bending the trunk. The object itself is important, of course, regarding its bulk, its pliability (e.g., firm box versus pliable bag), and whether it can be grasped securely (shape, handles). Naturally, the workplace itself must be well designed and maintained. Important aspects are: proper working height; material provided in containers from which it can be removed easily; nonslip floor and a clean, orderly environment that is free of avoidable noise and climate stressors.

Other publications address these issues in great detail (see Christensen & Manuele, 1999; Kroemer, 1997; Kroemer et al, 2001); therefore, only Keys 5 and 7 will be treated here.

Training

TRAINING IN PROPER LIFTING TECHNIQUES

Instructions on how to lift are meant to improve lifting technique and behavior and thus to reduce the likelihood of an overexertion strain or injury. In the laboratory, it has been shown that training regimens can increase the ability for lifting. Sharp and Legg (1988) reported that after four weeks of training, initially inexperienced lifters increased their work output significantly while maintaining their energy expenditures. The improvement was attributed to better skill through improved neuromuscular coordination and to possible increases of muscular endurance. Genaidy et al (1990) used six weeks of training and also found that muscular endurance, muscular strength, and cardiovascular endurance were improved. Yet, to date, there have been no reports of tightly controlled studies with large numbers of industrial material handlers, and the validity of laboratory findings for industrial environments has not been established.

WHAT TO TRAIN?

From the 1940s on, the advocated lift method was the *straight-back/bent-knees lift* (*squat lift*), in which workers lowered themselves to the load by bending the knees and then lifted by using the leg muscles. Yet, results of biomechanical and physiological research have shown that the leg muscles used in this lift method do not always have the needed strength. Also, awkward and stressful postures may be assumed if one tries to enforce this technique under unsuitable circumstances, e.g., when the object is bulky. Hence, the straight-back/bent-knees action evolved into the so-called *kinetic lift*, in which the back is kept mostly straight while the knees are unbent; but feet, chin, arm, hand, and torso positions are prescribed. Another variant was the free-style lift that appeared to be better for some workers than the straight-back/bent-knees technique. In some situations the stoop lift (with a strong bend at the waist and straight knees) may be superior to the squat (bent knees, flat back) posture, which is usually advocated. Sedgwick and Gormly (1998) discussed the suitability of leg and stoop lifts and believed

that an intermediate "semi-squat" lift was most versatile. The contradictory findings confirm Jones' 1972 statement that no single lifting method is best for all situations. Therefore, training of proper lifting technique is an area of confusion: What method should be taught?

UNSUCCESSFUL TRAINING

Reviews by Brown (1972, 1975), Snook (1988), and Yu et al (1984) detected no significant reductions in back injury as a result of training during a four-decade period. Several studies on nurses did not find effects on the incidence of low-back injury after receiving repeated instruction on lifting procedures; the principles taught were seldom used (Torres, 1998). Although neither the quality nor the content of the programs was investigated, the general conclusion was that training was not an effective preventive program for low-back injuries. Scholey and Hair (1989) reported that 212 physical therapists involved in back care education had the same incidence, prevalence, and recurrence of back pain as a carefully matched control group.

SUCCESSFUL TRAINING

In 1981 Hayne suggested that the three essential components of a training program are "knowledge, instruction, and practice," but did not provide sufficient information on the contents of such a program nor indicate how to make reliable evaluations of its effectiveness. Davies (1978) reported decreases in back-injury incidence after three carefully designed and properly carried-out training programs. Miller (1977) reported success in decreasing the frequency of back injuries by using a five-minute slide/cassette program, a film, and posters to emphasize the theme "when you lift, bend your knees." A cohort was not observed.

"BACK SCHOOLS"

The back-school concept is often traced to Fahrini (1975), who suggested education as a conservative treatment for low-back pain patients, as opposed to surgery. He began using this form of treatment as early as 1958; other schools have since developed and in the 1980s health-care providers, physicians, nurses, and physical therapists popularized these schools for rehabilitation of patients with back injuries. This training approach emphasizes knowledge, awareness, and attitude change by instructing the individual in anatomy, biomechanics, and injuries of the spine. The overall goal is to encourage the individual to take responsibility for his or her own health by means of proper nutrition, physical fitness, and awareness of the effects of posture and movement on the back. Such programs may also provide vocational guidance and information on stress management, even on drug use and abuse.

Controlled research concerning back schools has been limited, but back-school patients usually express increased understanding of their own back problem and a feeling of better control of pain after attending.

Typical industrial case studies of training involve use of a training program, new safety rules and job redesign, and a "publicity" effort using posters, booklets, and paycheck stuffers. Reported results frequently indicate large reductions in compensation costs and fewer lost workdays per injury. However, these studies do not usually include a control group. One exception is a study of 3,424 employees of the Boeing Company by Battie et al (1989), who found that in this study no significant differences in the occurrence of back pain nor in the number of lost work days between (healthy) employees who attended back school and a control group that did not.

Only a few reports on the effectiveness of training mention control groups; according to these, back school therapy was successfully applied to patients with back pain. Daltrov et al (1997) conducted a controlled study with nearly 4,000 postal employees. Experienced physical therapists trained 2,534 workers and 134 supervisors. Work units of workers with their supervisors participated in a two-session back school (three hours of training) followed by three to four reinforcement sessions over the next five years. Persons from either the intervention or the control groups who were injured during that time period were randomized again to receive either training or not after return to work. During the observation period of more than five years, 360 persons reported back injuries: the rate was 21.2 injuries per 1,000 worker-years of risk. The median time off work was 14 days, the median cost $204. A comparison of the intervention and control groups showed no effects of the education program on the rate of low back injuries, the cost per injury, the time off work per injury, or the rate of injury repetition. Curiously, the trainees showed an increased knowledge of safe behavior.

TRAINING FOR FITNESS AND FLEXIBILITY

Physical fitness training is a related approach to training workers in prevention of low-back injury. Material handling is physical work, and it is reasonable to assume that many aspects of physical fitness, especially musculoskeletal strength, aerobic capacity, and flexibility may be associated with the ability to perform load handling without injury. Exercise has been used in the treatment of back injury for many years, although its exact role and effectiveness are not completely understood.

Musculoskeletal strength, one aspect of physical fitness, is generally believed to be related to back injury. Experience seems to indicate that the occurrence of musculoskeletal injuries in weaker workers is greater than that for stronger workers. But there is the unexpected finding that "strong" persons may be more often injured than their weaker colleagues (Battie et al, 1989). Although the concept of strength training within an industrial environment as a means of back injury prevention is occasionally mentioned, at the time of this writing, we could not locate major research literature on this topic.

Flexibility, particularly of the trunk, appears to be needed for bending and lifting activities, which are part of material handling tasks. Chenoweth (1983a, 1983b) reported that an

industrial fitness program was successful with volunteer participants, compared to their control-group worker colleagues. Unfortunately, the control group seems not to have been selected from volunteers. An empirical study of 1,652 Los Angeles County firefighters investigated the relationship between fitness and low-back injury to determine the relationships between five strength and fitness measures with the occurrence of back injury over a three-year period (Cady et al, 1979a, 1979b). Individuals were rated to be on one of three levels of fitness (high, middle, or low) based on measurements of flexibility, isometric lifting strength, recovery heart rate, blood pressure, and endurance. The results show that the fittest firefighters had the lowest percentage of back injuries and the least fit group the largest percentage; but the fittest had the most severe injuries. This study often has been used to suggest that physical fitness may help to prevent back injuries, but Nordin (1991) cited two more recent longitudinal studies that did not show an association between fitness level (measured via maximal oxygen uptake) and reported back pain. Nordin stated that flexibility measures were found to be poor predictors of back problems.

Regaining and improving fitness, including flexibility, while recovering from a back injury or other disability has always been of concern to patients and their health caretakers. Parts of the back-school concept have been incorporated in *work hardening*, where specific body abilities deemed necessary to perform the job are improved through purposeful designed exercises. Fitness training for preventing back injury is viewed with great interest; to date, however, there is not enough evidence on the effectiveness of this approach in general, or on specific programs to support its effectiveness.

CONTENT OF TRAINING

A basic question, "What to teach?" has not yet been answered: the content of a training course depends on its aims. Previous efforts usually were in three areas;

1. Training specific lifting techniques, i.e., skill improvement.
2. Teaching biomechanics, awareness of and self-responsibility for back injuries, thereby changing attitudes.
3. Making the body physically fit so that it is less susceptible to injury.

Although the aim, injury prevention, is the same in each case, the methods of how to achieve that aim are quite different. The traditional approach of training a specific lifting technique alone does not appear effective, mainly because there is no one technique appropriate for all lifts. Most courses are therefore considered "unrealistic" and centered too much on protecting the back, as Sedgwick and Gormly (1998) reported from consensus meetings with more than 900 Australian health professionals—yet, they proposed to teach "semi-squat" lifting throughout their course.

Preventing injury by increasing knowledge of the body and promoting attitude changes so that workers feel responsible for their bodies has a basic, almost simplistic, appeal and should be quite applicable. However, exactly what should be taught, and how, is still open. How much knowledge is needed of kinesiology, biomechanics, physiology? What method is most effective? Barker and Atha (1994) reported that written guidelines, such as commonly handed to untrained industry personnel, worsened lifting performance.

Another key to awareness and attitude change may be the attention paid to material handling problems by management, supervisors, or training instructors. Making employees aware of management's concern is an underlying theme in the training received from back schools.

WHO TO TRAIN

Most industrial back injuries are not associated with objective pathological findings, and about every second back pain episode cannot be linked to a specific incident Yet, many actions and events at work are associated with low-back injuries. In the mining industry, overexertion, slips/trips/falls, and jolts in vehicles are the most frequently mentioned events (Bobick & Gutman 1989). Back injuries have been directly associated with lifting (37% to 49% of the cases), pulling (9% to 16%), pushing (6% to 9%), carrying (5% to 8%), lowering (4% to 7%), bending (12% to 14%), twisting (9% to 18%). The percentages vary considerably among industries and occupations. Construction and mining industries have reported the largest incidence ratios for compensation claims for back injuries. Other ccupations with high ratios were garbage collectors, tire makers, truck drivers, nurses, and, as expected, material handlers.

Load handling specifics differ much among industries and jobs (tire-making, mining, nursing) as well as within one industry or profession. They depend on the specific task, on available handling aids and equipment, and on many other conditions. Therefore, it is a question of how training recommendations are applied across settings. Even the group characteristics of material handlers in different industries might be important in designing a training program. For example, hospital workers might have higher educational skills than heavy-industry workers. Female employees may predominate in a given industry or occupation, which might influence the type of training, because usually women are about two-thirds as strong as men. It is not known how personal or task-specific characteristics should influence training.

In the United States, only about 2 of every 100 employees report a back injury per year. This poses another problem regarding the effectiveness and cost of back-care instructions. Of the actually reported injuries, about every tenth is serious, yet these few serious injuries cause the largest portion of the total cost. Hence, to prevent specifically these serious injuries, 2 of every 1,000 employees would be the target sample, while all 1,000 must be in the educational program. Even to address all persons who may suffer from any kind of back problem, about 20 out of 1,000, this is still a rather expensive approach, which may not appear cost-effective to the administrator.

Most training targets the individual worker or groups of workers. But one can also educate supervisors, health and safety professionals, and management personnel in:

- ➢ awareness of load-handling problems
- ➢ ergonomic job design principles
- ➢ how to respond to low-back pain and injury once it has occurred.

Such supervisor and manager training is probably important for an effective injury prevention program—but there are no actual data to support that.

REVIEW OF TRAINING

Immediately after training, there can be an increase in the incidences of reported pain. This can be attributed to a change in management attitude and a willingness on the part of employees to report back problems early—positive steps toward avoiding more serious injury.

With currently available information, hardly any specific (or general) training guidelines are well supported by controlled research. This leaves much room for speculation, guesswork, and charlatanism regarding the "best" way to train people for the prevention of back injuries related to load handling. This condition is deplorable and needs to be remedied, since common sense indicates that training should be successful.

The issue of training to prevent back injuries in material handling still is confused, at best. Some, possibly most, training approaches are not effective in injury prevention, or their effects may be so uncertain and inconsistent that money and effort paid for training programs might be better spent on ergonomic job design. "In spite of more than 50 years of concerted effort to diminish task demand, the incidence of compensable back injuries has not wavered. Rather than pursuing the 'right way to lift,' the more reasonable and humane quest might be for workplaces that are comfortable when we are well and accommodating when we are ill" (Hadler 1997, p. 935).

The legal responsibility of employers to provide training cannot be ignored; thus, the idea to abandon material handling training appears unrealistic. "Yet so long as it is a legal duty [in the United States] for employers to provide such training or for as long as the employer is liable to a claim of negligence for failing to train workers in safe methods of MMH, the practice is likely to continue despite the lack of evidence to support it." (NIOSH 1981, p. 99)

If the job requirements are stressful, "doctoring the symptoms" such as behavior modification will not eliminate the inherent risk. Designing a safe job is fundamentally better than training people to behave safely. Yet it appears plausible to expect that at least certain training approaches should show positive results. Among these, training for:

- ➢ "lifting skills" (body and load positioning and movement)
- ➢ "awareness and attitude" (physics and biomechanics associated with lifting, self-control)
- ➢ "fitness, strength and endurance"

appeal to common sense and appear theoretically sound, even though none of these has yet proven successful according to the literature. It appears plausible that back pain may be related to job satisfaction and attitude. This finding generates important questions regarding psychosociological aspects on and off the job which, so far, have found few answers.

DESIGN OF WORK TASK AND WORKPLACE

The first design decision is to allocate load-handling tasks to either machines or humans. If people must handle material, then the specific job requirements must be analyzed.

Human versus Machine Load Handling

For the initial design decisision, the *unit size principle* is of particular interest. According to it, one can either increase the quantity (size, weight) of the unit load so that equipment use becomes feasible and appropriate for the movement of material—this is the *big unit outcome*. Or one may reduce the size and weight of the load so that one operator can safely handle the material—this is the *small unit outcome*.

If all opportunities to automate or mechanize the movement of material have been exhausted, some material handling may have to be assigned to people. In this case, establish job requirements that will not overload the person or pose possible hazards. One must organize the task, establish job procedures, and determine details to enable the operator to perform the work safely and efficiently. Here are some guidelines:

- ➢ If people must move material, make sure the movement is predominantly in the horizontal plane. Push and pull, rather than lift or lower, and avoid severe bending of the body.
- ➢ If people must lift or lower material, let them do so between knuckle height and shoulder height. Lifting and lowering below knuckle height or above shoulder height are most likely to result in overexertion injuries.
- ➢ If lifting and lowering must be done by people, make sure these activities occur close to and in front of the body. If the worker must bend forward or, worse, twist the body sideways, overexertion injuries are most likely.
- ➢ If people must move material, make sure the material is light, compact, and safe to grasp. A light object will strain the spinal column and body tissues less than heavy objects. Compact material can be held more closely to the body than a bulky object. A solid object with good handles is more safely held and more easily moved than pliable material.
- ➢ If people must handle material, make sure it does not have sharp edges, corners, or pinch points.
- ➢ If material is delivered in bins or containers, make sure it can be easily removed from them, particularly that the operator does not have to "dive" into the container to reach the material.
- ➢ People tend to revert to previous habits and customs if practices to replace previous ones are not reinforced and refreshed periodically.

- ➢ Emergency situations, the unusual case, the sudden quick movement, increased body weight, or impaired physical well-being may overly strain the body, since training usually does not include these conditions.
- ➢ If the job requirements are stressful, "doctoring the system" through behavioral modification will not eliminate the inherent risk. Designing a safe job is basically better than training people to behave safely in an unsafe job.

Rules for Lifting

There are no comprehensive and sure-fire rules for "safe" lifting. Manual load handling is a very complex combination of moving body segments, changing joint angles, tightening muscles, and loading the spinal column. The following DOs and DO NOTs appear helpful, however:

- ➢ DO design manual lifting and lowering out of the task and workplace. If a worker nevertheless must do it, perform it between knuckle and shoulder height.
- ➢ DO be in good physical shape. If you are not used to lifting and vigorous exercise, do not attempt to do difficult lifting or lowering tasks.
- ➢ DO think before acting. Place material conveniently within reach. Have handling aids available. Make sure sufficient space is cleared.
- ➢ DO get a good grip on the load. Test the weight before trying to move it. If it is too bulky or heavy, get a mechanical lifting aid or somebody else to help, or both.
- ➢ DO get the load close to the body. Place the feet close to the load. Stand in a stable position with the feet pointing in the direction of movement. Lift mostly by straightening the legs.
- ➢ DO NOT twist the back or bend sideways.
- ➢ DO NOT lift or lower awkwardly.
- ➢ DO NOT hesitate to get mechanical help or help from another person.
- ➢ DO NOT lift or lower with the arms extended.
- ➢ DO NOT continue heaving when the load is too heavy.

Permissible Load Handling

Tables of lift weights for men, women, and children, were used in the United States until the National Institute of Occupational Safety and Health (NIOSH) *Work Practices Guide for Manual Lifting* appeared in 1981. Since then new knowledge about human material handling capabilities has been gained, based on epidemiological, medical, physiological, biomechanical, and psychological approaches. However, even new guidelines are still based on assumptions and approaches that need refinement and further evaluation.

Limits for Lifting and Lowering

In 1981, a panel of experts prepared for the U.S. NIOSH a *Work Practices Guide for Manual Lifting* (NIOSH, 1981). For the first time, this document contained distinct recommendations for acceptable masses to be lifted.This differed from the previous assumptions that one could establish just one given weight each for men, women, or children that would be safe to lift. This 1981 NIOSH guide established two different threshold curves. The lower, called *Action Limit* (*AL*) was thought to be safe for 99 percent of working men and 75 percent of women in the United States. The AL values depended on the starting height of the load, the length of its upward path, its distance in front of the body, and the frequency of lifting. If the existing weight was above the AL value, engineering or managerial controls had to be applied to bring the load value down to the acceptable limit. However, under no circumstances was lifting allowed if the load was three times larger than the action limit values. This threshold was called the *Maximum Permissible Load* (*MPL*).

A decade later, NIOSH revised the technique for assessing overexertion hazards of manual activity (Putz-Anderson & Waters, 1991; Waters et al, 1993, Waters et al, 1998, 1999). The new NIOSH guideline no longer contains two separate weight limits, but has only one *Recommended Weight Limit* (*RWL*). It represents the maximal weight of a load that may be lifted or lowered by about 90 percent of American industrial workers, male or female, physically fit and accustomed to physical labor.

The 1991 equation used to calculate the RWL resembles the 1981 formula for AL, but includes new multipliers to reflect asymmetry and the quality of hand-load coupling. Yet, the 1991 equation allows as maximum a *load constant* (LC), permissible only under the most favorable circumstances, with a value of 23 kg (51 lb). This is quite a reduction from the maximal 40 kg in the 1981 NIOSH guidelines.

The following assumptions and limitations apply:

- ➢ The equation does NOT include safety factors for such conditions as unexpectedly heavy loads, slips, or falls, or for temperatures outside the range of 19 C (66 F) to 26 C (79 F) and for humidity not within 35 to 65 percent.
- ➢ The equation does NOT apply to one-handed tasks while seated or kneeling, or to tasks in a constrained workspace.
- ➢ The equation assumes that other manual handling activities and body motions requiring high energy expenditure such as in pushing, pulling, carrying, walking, climbing, or static efforts as in holding, are less than 20 percent of the total work activity for the work shift (Waters, 1991).
- ➢ The equation assumes that the worker/floor surface coupling provides a coefficient of static friction of at least 0.4 between the shoe sole and the standing surface.
- ➢ The equation may be applied under the following circumstances:
  - ➢ Lifting or lowering tasks, i.e., the acts of manually grasping and moving an object of definable size without mechanical aids to a different height level.
  - ➢ The time duration of such an act is normally between two and four seconds. The load is grasped with both hands.
  - ➢ The motion is smooth and continuous.

- ➢ The posture is unrestricted (see above).
- ➢ The foot traction is adequate (see above).
- ➢ The temperature and humidity are moderate (see above).
- ➢ The horizontal distance between the two hands is no more than 65 cm (25 in.).

For these conditions, NIOSH provides an equation for calculating the Recommended Weight Limit (RWL):

$$RWL = LC \bullet HM \bullet VM \bullet DM \bullet AM \bullet FM \bullet CM \quad (22)$$

LC is the Load Constant of 23 kg (51 lb).
Each multiplier can assume values between zero and one:
HM represents the Horizontal Multiplier where *H* is the horizontal location (distance) of the hands from the mid-point between the ankles at the start and at the end points of the lift.
VM is the Vertical Multiplier where *V* is the vertical location (height) of the hands above the floor at the start and end points of the lift.
DM is the *Distance Multiplier* where *D* is the vertical travel distance from the start to the end points of the lift.
AM is the *Asymmetry Multiplier* where *A* is the angle of asymmetry, i.e., the angular displacement of the load from the medial (midsagittal plane), which forces the operator to twist the body. It is measured at the start and end points of the lift, projected onto the floor.
FM is the *Frequency Multiplier* where *F* is the frequency rate of lifting, expressed in lifts per minutes. It depends on the duration of the lifting task.
CM is the *Coupling Multiplier* where *C* indicates the quality of coupling between hand and load.

The following values are entered in the equation for RWL:

	Metric	*U.S. Customary*
LC = Load constant =	23 kg	51 lb
HM = Horizontal multiplier =	25/*H*	10/*H*
VM = Vertical multiplier =	1 – (0.003|*V*–75|)	1 – (0.0075|*V*–30|)
DM = Distance multiplier =	0.82 + (4.5/*D*)	0.82 + (1.8/*D*)
AM = Asymmetry multiplier =	1 – (0.0032*A*)	1 – (0.0032*A*)
FM = Frequency multiplier (see listing below)		
CM = Coupling multiplier (see listing below)		

These variables can have the following values:

H is between 25 cm (10 in.) and 63 cm (25 in.). Although objects can be carried or held closer than 25 cm in front of the ankles, most objects that are closer cannot be lifted or lowered without encountering interference from the abdomen. Objects farther away than 63 cm (25 in.) cannot be reached and cannot be lifted or lowered without loss of body balance, particularly when the lift is asymmetrical and the operator is small.

V is between zero and (175–*V*) cm [(70–*V*) in.] because few people can lift higher.
For a lifting task, $D = V_{end} - V_{start}$; for
a lowering task, $D = V_{start} - V_{end}$.

A is between 0° and 135°.

F is between one lift or lower every five minutes (over a working time of eight hours) to 15 lifts or lowers every minute (over a time of one hour, or less), depending on the vertical location V of the object. Table 13–H lists the Frequency Multipliers (FM).

C is between 1.00 ("good") and 0.90 ("poor"). The effectiveness of the coupling may vary as the object is being lifted or lowered: a "good" coupling can quickly become "poor". Three categories are defined in detail in the NIOSH publication and result in the following listing of values for the Coupling Multiplier CM:

Couplings	*V < 75 cm (30 in.)*	*V = 75 cm (30 in.)*
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

To help apply the 1991 NIOSH recommended weight limit, a *Lifting Index* (LI) is calculated: LI = *L*/RWL, with *L* the actual load. If LI is at or below one, no action must be taken. If LI exceeds one, the job must be ergonomically redesigned.

Limits for Lifting, Lowering, Pushing, Pulling, and Carrying

In 1978, Snook published extensive tables of loads and forces found acceptable by male and female workers for continuous manual material handling jobs. These data were first updated in 1983 by Ciriello and Snook, then revised in 1991 by Snook and Ciriello and in 1993 by Ciriello, Snook, and Hughes (Tables 13–I to 13–M). The following prerequisites apply for the application of their data:

- ➢ Two-handed symmetrical material handling in the medial (midsagittal) plane, i.e., directly in front of the body; yet, a light body twist may occur during lifting or lowering
- ➢ moderate width of the load such as 75 cm or less
- ➢ good couplings, of hands with handles, shoes with floor
- ➢ favorable physical environment, such as about 21 degrees C at a relative humidity of 45 percent
- ➢ only minimal other physical work activities
- ➢ material handlers who are physically fit and accustomed to labor.

The format of the recommendations of Ciriello, Snook, and Hughes differs from the layout of the NIOSH guidelines. The NIOSH values are unisex, while the Ciriello et al data are separated for female and males. The Ciriello et al (1993) data are also grouped by the percentages of the worker population to whom the values are acceptable. The data do not indicate individual capacity limits; rather, they represent the opinions of more than 100 experienced material handlers as to what they would do willingly and without overexertion.

Tables 13–I through 13–M show, in much abbreviated form, the recommendations of Ciriello et al for suitable loads and forces in lifting, lowering, pushing, pulling, and carrying. The tables are shown here only as examples; the original tables as updated in 1993 by Ciriello, Snook, and Hughes must be consulted for complete information.

Table 13–H. *Frequency Multipliers for the 1991 NIOSH Equation*

	Work Duration (Continuous)					
	≤8 h		≤2 h		≤1 h	
Frequency, lifts/min	V < 75*	V ≥ 75	V < 75	V ≥ 75	V < 75	V ≥ 75
0.2	0.85	0.85	0.95	0.95	1.00	1.00
0.5	0.81	0.81	0.92	0.92	0.97	0.97
1	0.75	0.75	0.88	0.88	0.94	0.94
2	0.65	0.65	0.84	0.84	0.91	0.91
3	0.55	0.55	0.79	0.79	0.88	0.88
4	0.45	0.45	0.72	0.72	0.84	0.84
5	0.35	0.35	0.60	0.60	0.80	0.80
6	0.27	0.27	0.50	0.50	0.75	0.75
7	0.22	0.22	0.42	0.42	0.70	0.70
8	0.18	0.18	0.35	0.35	0.60	0.60
9	0	0.15	0.30	0.30	0.52	0.52
10	0	0.13	0.26	0.26	0.45	0.45
11	0	0	0	0.23	0.41	0.41
12	0	0	0	0.21	0.37	0.37
13	0	0	0	0	0	0.34
14	0	0	0	0	0	0.31
15	0	0	0	0	0	0.28
>15	0	0	0	0	0	0

* *V* is expressed in centimeters.

(From Putz-Andersson & Waters, 1991.)

Note that, similar to NIOSH recommendations, the data in the Snook and Ciriello studies also indicate that lack of handles reduces the loads that people are willing to lift and lower by an average of about 15 percent. If the objects become so wide or so deep as to be difficult to grasp, the lifting and lowering values are again considerably reduced. If several material handling activities occur together, the most strenuous task establishes the handling limit.

If actual loads or forces exceed table values, engineering or administrative controls should be applied. Snook believes

Table 13–I. *Maximal Acceptable Lift Weights (kg)*

			Floor Level to Knuckle Height								Knuckle Height to Shoulder Height								Shoulder Height to Overhead Reach							
			One Lift Every								One Lift Every								One Lift Every							
			s			min				h	s			min				h	s			min				h
Width*	Distance**	Percent†	5	9	14	1	2	5	30	8	5	9	14	1	2	5	30	8	5	9	14	1	2	5	30	8
	Males																									
		90	9	10	12	16	18	20	20	24	9	12	14	17	17	18	20	22	8	11	13	16	16	17	18	20
34	51	75	12	58	18	23	26	28	29	34	12	16	18	22	23	23	26	29	11	14	17	21	21	22	24	26
		50	17	20	24	31	35	38	39	46	15	20	23	28	29	30	33	36	14	18	21	26	27	28	31	34
	Females																									
		90	7	9	9	11	12	12	13	18	8	8	9	10	11	11	12	14	7	7	8	9	10	10	11	12
34	51	75	9	11	12	14	15	15	16	22	9	10	11	12	13	13	14	17	8	8	9	11	11	11	12	14
		50	11	13	14	16	18	18	20	27	10	11	13	14	15	15	17	19	9	10	11	12	13	13	14	17

* Handles in front of the operator (cm).

** Vertical distance of lifting (cm).

† Acceptable to 50, 75, or 90 percent of industrial workers.

(Adapted from Snook & Ciriello, 1991.)

Table 13–J. *Maximal Acceptable Lower Weights (kg)*

			Knuckle Height to Floor Level — One Lower Every								Shoulder Height to Knuckle Height — One Lower Every								Overhead Reach to Shoulder Height — One Lower Every							
			s			min				h	s			min				h	s			min				h
Width*	Distance**	Percent†	5	9	14	1	2	5	30	8	5	9	14	1	2	5	30	8	5	9	14	1	2	5	30	8
	Males																									
		90	10	13	14	17	20	22	22	29	11	13	15	17	20	20	20	24	9	10	12	14	16	16	16	20
34	51	75	14	18	20	25	28	30	32	40	15	18	21	23	27	27	27	33	12	14	17	19	22	22	22	27
		50	19	24	26	33	37	40	42	53	20	23	27	30	35	35	35	43	16	19	22	24	28	28	28	35
	Females																									
		90	7	9	9	11	12	13	14	18	8	9	9	10	11	12	12	15	7	8	8	8	10	11	11	13
34	51	75	9	11	11	13	15	16	17	22	9	11	11	12	14	15	15	19	8	9	10	10	12	13	13	16
		50	10	13	14	16	18	19	20	27	11	13	13	14	16	18	18	22	10	11	11	12	14	15	15	19

* Handles in front of the operator (cm).

** Vertical distance of lowering (cm).

† Acceptable to 50, 75, or 90 percent of industrial workers.

(Adapted from Snook & Ciriello, 1991.)

that industrial back injuries could be reduced by about one third if the loads that lie above the values acceptable to 75 percent of the material handlers could be eliminated.

COMPARING NIOSH WITH THE CIRIELLO ET AL RECOMMENDATIONS

The guidelines by NIOSH are based mostly on biomechanical considerations, particularly referring to a threshold compression of force in the lower spine of 3,400 N, with some consideration of physiological strains. The calculation of the RWL of the lifting or lowering is done twice, once for the beginning point, and again for the ending point.

The guidelines by Ciriello et al, in contrast, rely on the psychophysical assessments of experienced industrial material handlers performing controlled material handling activities in the laboratory. These activities go beyond lifting and lowering;

Table 13–K. *Maximal Acceptable Push Forces (N)*

			One 2.1-m Push Every									One 30.5-m Push Every						
	Height (a)	Percent (b)	6	12	1	2	5	30	8		Height (a)	Percent (b)	1	2	5	30	8
			s		min				h				min				h
										Initial Forces							
Males	95	90	206	235	255	255	275	275	334		95	90	167	186	216	216	265
		75	275	304	334	324	353	353	432			75	206	235	275	275	343
		50	334	373	422	422	442	442	530			50	265	294	343	343	432
Females	89	90	137	147	167	177	196	306	216		89	90	118	137	147	157	177
		75	167	177	296	216	235	245	265			75	147	157	177	186	206
		50	196	216	245	255	285	294	314			50	177	196	206	226	255
										Sustained Forces							
Males	95	90	98	128	159	167	186	186	226		95	90	79	98	118	128	157
		75	137	177	216	216	245	255	304			75	108	128	157	177	206
		50	177	226	225	285	324	335	392			50	147	167	196	226	265
Females	89	90	59	69	88	88	98	108	128		89	90	49	59	59	69	88
		75	79	106	128	128	147	157	186			75	79	88	88	98	128
		50	168	147	177	177	196	206	255			50	98	118	118	128	167

(a) Vertical distance from floor to hands (cm).

(b) Acceptable to 50, 75, or 90 percent of industrial workers.

Conversion: 1 kg_f = 2.2 lb_f = 9.81 N. 1 cm = 0.4 in.

Note that this is only an excerpt. Please see the complete table from Ciriello et al, *Hum Factors* 35:175–186, 1993.

(Adapted from Ciriello, Snook, and Hughes, 1993.)

Table 13–L. *Maximal Acceptable Pull Forces (N)*

	Height (a)	Percent (b)	One 2.1-m Pull Every: 6 s	12 s	1 min	2 min	5 min	30 min	8 h
						Initial Pull			
		90	186	216	245	245	265	265	314
Males	95	75	226	265	304	304	314	324	383
		50	275	314	353	353	383	383	461
		90	137	157	177	186	206	216	226
Females	89	75	157	186	206	216	245	255	265
		50	186	226	245	255	285	294	314
						Sustained Pull			
		90	98	128	157	167	186	196	235
Males	95	75	128	167	206	216	245	255	294
		50	157	206	255	265	304	314	363
		90	59	88	98	98	108	118	137
Females	89	75	79	118	128	128	147	157	196
		50	98	147	157	167	186	196	245

(a) Vertical distance from floor to hands (cm).

(b) Acceptable to 50, 75, or 90 percent of industrial workers.

Conversion: 1 kg_f = 2.2 lb_f = 9.8 N. 1 cm = 0.4 in.

Note that this is only an excerpt. Please see the complete table from Ciriello et al, *Hum Factors* 35:175–186, 1993.

(Adapted from Ciriello, Snook, and Hughes, 1993.)

they also include pushing/pulling, carrying, and holding. Thus, the Ciriello et al tables have wider applicability than what can be calculated from the NIOSH formula.

Direct comparisons are possible only between the lifting and lowering recommendations. In general, the results are quite similar, however, with some larger deviations in the extremes of frequencies. To be prudent one should take the lower values of either set of recommendations.

In general, one should prefer pushing and pulling to carrying, and to lifting and lowering. Figure 13–14 schematically shows engineering interventions applied to solve the problems associated with material handling. The main intent is to eliminate or at least to reduce the overexertion injury risks to material handlers. Kroemer et al (2001) provide detailed recommendations for activities other than industrial material handling, including outdoors load transport or moving of patients in hospitals and nursing homes. They also discuss ergonomic selection of material transport and handling equipment, and the design and use of trays and containers.

Use of Back Belts

When preparing to lift or lower a load, we instinctively

Table 13–M. *Maximal Acceptable Carrying Weights (kg)*

	Height*	Percent**	One 2.1-m Carry Every: 6 s	12 s	1 min	2 min	5 min	30 min	8 h
		90	13	17	21	21	23	26	31
Males	79	75	18	23	28	29	32	36	42
		50	23	30	37	37	41	46	54
		90	13	14	16	16	16	16	22
Females	72	75	15	17	18	18	19	19	25
		50	17	19	21	21	22	22	29

* Vertical distance from floor to hands (cm).

** Acceptable to 50, 75, or 90 percent of industrial workers.

Note that this is only an excerpt. Please see the complete table from Snook et al, *Ergonomics* 34:1197–1213, 1991.

(Adapted from Ciriello, Snook, and Hughes, 1993.)

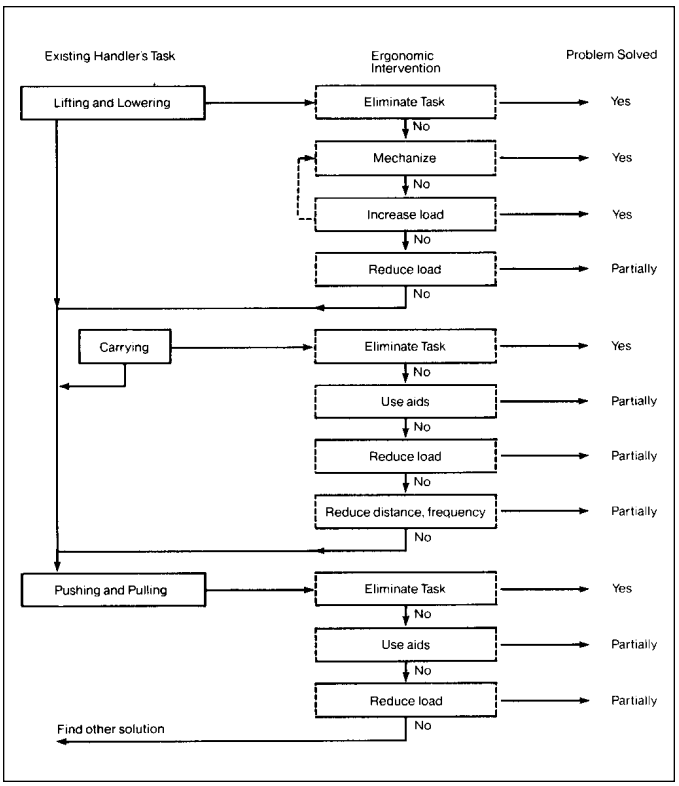

Figure 13–14. Reducing overexertion risks in material handling.

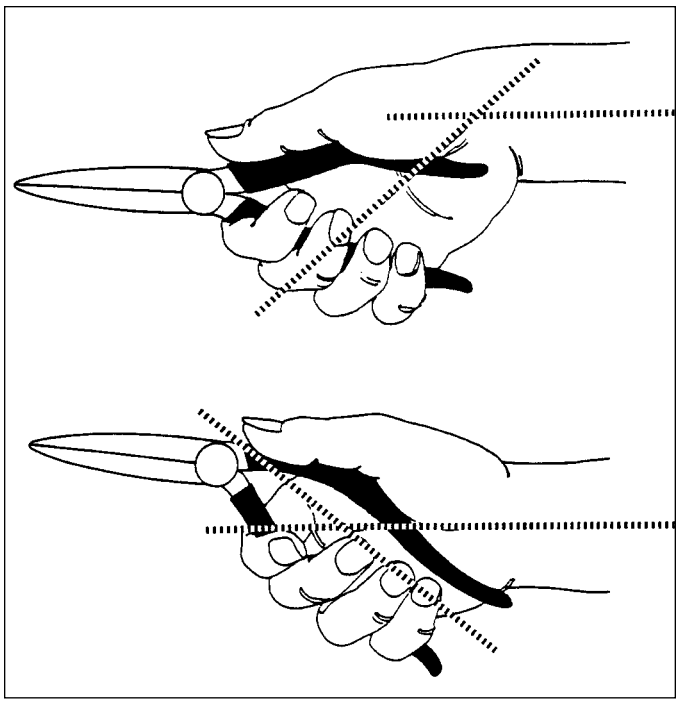

Figure 13–15. "Common" and "ergonomic" pliers. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency.* Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

develop intra-abdominal pressure within the trunk cavity. This pressure is believed to help support the curvature of the spine during the lifting or lowering effort. An external wrapping around the abdominal region might help to maintain this internal pressure because it makes the walls of the pressure column stiffer. Porters and workers in Nepal traditionally wear a cloth wound around the waist, called *patuka*, while weight lifters commonly use fairly stiff, wide and contoured belts. It has been advocated that people who do heavy manual material handling should also wear such abdominal belts (called variously back belts, lift belts, back braces, or back supports). A large number of studies have been performed, summarized, and reviewed by McGill (1999), Lavender et al (1998), and Thoumier et al (1998). Their conclusions neither summarily support nor condemn the wearing of support belts in industrial jobs.

- ➢ Certain material handlers, especially persons who have suffered a back injury, may benefit from a suitable belt.
- ➢ Candidates for belt wearing should be screened for cardiovascular risk, which may be increased by belt pressure.
- ➢ Belt wearers should receive training similar to that given in back school because the presence of the belt may provide a false sense of security.
- ➢ Belts should not be considered for long-term use.
- ➢ Belts are not a substitute for ergonomic design of work task, workplace, and work equipment.

Altogether, the use of lifting belts for professional material handling does not seem to be an effective way of preventing overexertion injuries: even competitive weight lifters do suffer back injuries.

HAND TOOLS

Many hand tools are really extensions of the hand. Pliers, for example, amplify the hand's strength, extend its reach, and protect sensitive tissues. Other tools are used to perform tasks that the hand cannot do—such as soldering—but they are held and directed by the hand. Too often design efforts have been focused on the working end of the tool rather than how it interfaces with the hand. Some hand tools are difficult to use because of inappropriate design, for instance, if the wrist is forced to bend, or because of pressure points between the hand and the handle. Many of our everyday hand tools are acceptable if we use them only occasionally, but must be redesigned for frequent handling over long periods of time, such as in occupational tasks where hand tools are used as part of the job. Figure 13–15 shows an example of straight-nose pliers that require an acute bend in the wrist because, as shown, the line of thrust of a hand tool is at approximately 30 degrees from the line of thrust of the forearm. Hence, one should bend a handle so that the wrist can be straight. Furthermore, fitting the handle surface to the enclosing surfaces of the hand helps to hold the tool securely and to employ it efficiently.

There are many ways to manipulate an object. Figure 13–16 organizes these from a simple touch applied by finger, or

1. Finger Touch: One finger touches an object without holding it.

2. Palm Touch: Some part of the inner surface of the hand touches the object without holding it.

3. Finger Palmar Grip (Hook Grip): One finger or several fingers hook(s) onto a ridge, or handle. This type of finger action is used where thumb counterforce is not needed.

4. Thumb-Fingertip Grip (Tip Grip): The thumb tip opposes one fingertip.

5. Thumb-Finger Palmar Grip (Pinch or Plier Grip): Thumb pad opposes the palmar pad of one finger (or the pads of several fingers) near the tips. This grip evolves easily from coupling #4.

6. Thumb-Forefinger Side Grip (Lateral Grip or Side Pinch): Thumb opposes the (radial) side of the forefinger.

7. Thumb-Two-Finger Grip (Writing Grip): Thumb and two fingers (often forefinger and index finger) oppose each other at or near the tips.

8. Thumb-Fingertips Enclosure (Disk Grip): Thumb pad and the pads of three or four fingers oppose each other near the tips (object grasped does not touch the palm). This grip evolves easily from coupling #7.

9. Finger-Palm Enclosure (Collet Enclosure): Most, or all, of the inner surface of the hand is in contact with the object while enclosing it.

10. Power Grasp: The total inner hand surface is grasping the (often cylindrical) handle which runs parallel to the knuckles and generally protrudes on one or both sides from the hand.

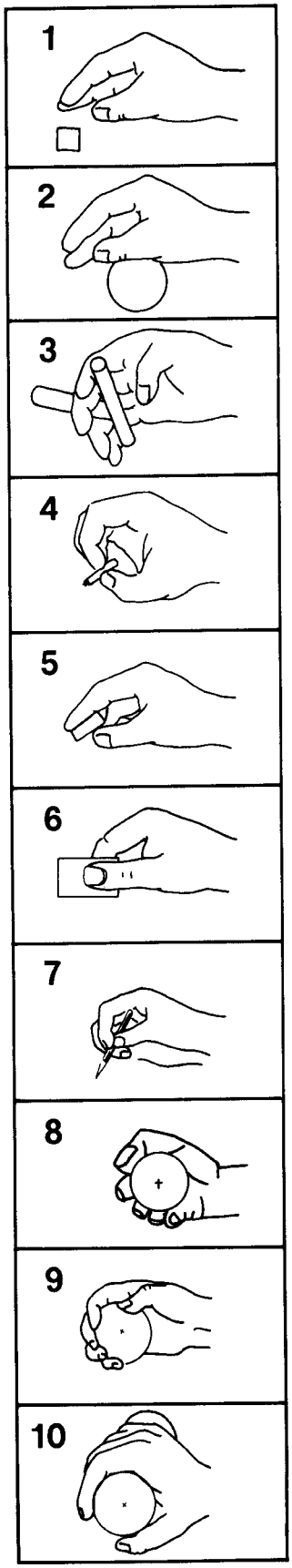

Figure 13–16. Couplings between hand and handle.

thumb, or palm (couplings 1 through 3) to tip and pinch grips (couplings 4 through 7) including the so-called "precision grip", to powerful grasps in which thumb, fingers, and palmar surfaces are involved (couplings 8 through 10). Any of these couplings evolves easily from the ones shown adjacently.

For the touch-type couplings, relatively little attention must be paid to fitting the surface of the handle to the touching surface of the hand. Yet, one may want to put a slight cavity into the top of a push button so that the fingertip does not slide off; to hollow out the handle of a scalpel slightly so that the tips of the digits can hold on securely; or to roughen the surface of a dentist's tool and, instead of making it round in cross-section, flatten it out or otherwise contour it for a secure hand-hold.

Such considerations of "secure tool handling" are most important for the enclosure couplings, which are used to transmit large energies between hand and tool. The tool designer's task is to make sure that the handle can be held securely (without fatiguing muscle unnecessarily, and avoiding pressure points) while one exerts linear force or rotating torque to it. In most tools, force must be applied by the hand in two directions: one perpendicular to the handle surface (e.g., by the palm closing the handles of pliers), the other perpendicular to that direction (in pulling an object with the pliers). Hence, both the cross-sectional and longitudinal shape of the tool must be considered. Furthermore, the presence of grease or dirt between the hand and handle or the wearing of gloves can have profound effects on the coupling.

Several publications address the problem of handle design. Chaffin et al, 1999; Cochran and Riley, 1986; Drury, 1980; Karwowski, 2001, Konz and Johnson, 2000; Mital, 1991, Woodson et al, 1991, Astin (1999), and Kroemer et al (2001) supply information about forces that can be generated by male operators in various hand-handle couplings; for female operators, about two thirds of these strengths can be expected—see Tables 13–N, 13–O, and 13–P.

Given the various tasks and uses of hand tools, only a few general guidelines can be provided; details have to be decided according to the given conditions:

- ➢ While manipulating the hand tool, the wrist should stay straight with respect to the forearm; that is, be neither rotated (pronated or supinated) nor bent (flexed-extended, laterally deviated). This often requires that the working side of the hand tool be at an oblique angle with the handle. (However, such special arrangement may make the tool useful only for certain tasks.)
- ➢ The handle should be of such cross-sectional size that the hand nearly encircles the handle, with no more space than about 1.3 cm (0.5 in.) between the fingertips and the thumb side. This means that the diameter, if circular, or the largest distance between two opposing sides of the handle should be between 2.5 and 6.5 cm (1.0–2.5 in.).
- ➢ The shape of the handle, in cross section, depends on the task to be performed; that is, on the motions involved in opening and closing the handle and on the magnitude of force or torque (moment) to be developed for use of the tool. In many cases, elliptical shapes (or rectangular ones with well-rounded edges) are advantageous if twisting (torquing or turning such as with screwdrivers) must be performed. However, more circular cross sections are preferred if the tool must be grasped in many different manners.
- ➢ The handle should easily accommodate the length of the hand in contact with it; for example, a knife handle should be at least as long as the hand enclosing it is broad. The contour of the handle can follow the contour of the inside of the hand enfolding the handle. However, strongly formfitting the handle shape might prevent people with different hand sizes or people who grasp the handle in a different way from handling the tool comfortably.
- ➢ Pressure points should be avoided. These are often present if the form of the handle has pronounced shape components, such as deep indentations for the fingers or sharp edges or contours.
- ➢ Rough surfaces of the handle might be uncomfortable for sensitive hands but can counteract the effects of grease that make the handle slippery.
- ➢ Flanges at the end of the handle can guide the hand to the correct position and prevent the hand from sliding off the handle.

Table 13–N. ***Average Digit Poke Forces* Exerted by 30 Subjects in Direction of the Straight Digits***

Digit	*10 Male Mechanics*	*10 Male Students*	*10 Female Students*
Thumb	83.8 (25.19) A	46.7 (29.19) C	32.4 (15.36) D
Index finger	60.4 (25.81) B	45.0 (29.99) C	25.4 (9.55) DE
Middle finger	55.9 (31.85) B	41.3 (21.55) C	21.5 (6.46) E

Entries with different letters are significantly different from each other ($p \leq 0.05$).

* Means and standard deviations, in *N*.

(Adapted from Kroemer, Kroemer, Kroemer-Elbert, *Ergonomics: How to Design for Ease and Efficiency*. Englewood Cliffs, NJ: Prentice Hall, 1994. Used with permission by the publisher. All rights reserved.)

Improperly designed hand tools, particularly when combined with ill-conceived workplaces and job procedures, can cause acute injuries to surface tissues and the musculoskeletal system of the hand-arm complex. Often, the repetition of biomechanical insults, each in itself insignificant, can lead to cumulative trauma disorders in the upper extremities, a major cause of lost work in many hand-intensive industries. Many of these disorders can be averted easily by paying attention to the following recommendations.

- ➢ Avoid repetitive or sustained exertions, particularly if they are accompanied by deviations from a straight wrist and/or by forceful exertions.

Table 13–O. *Grip and Grasp Forces* Exerted by 21 Male Students and 12 Machinists*

Couplings	*Digit 1 (Thumb)*	*Digit 2 (Index)*	*Digit 3 (Middle)*	*Digit 4 (Ring)*	*Digit 5 (Little)*	*All Digits Combined*
Push with digit tip in direction of the extended digit ("poke")	91 (39)** 138 (41)	52 (16)** 84 (35)	51 (20)** 86 (28)	35 (12)** 66 (22)	30 (10)** 52 (14)**	
Digit touch (Coupling #1) perpendicular to extended digit	84 (33)** 131 (42)	43 (14)** 70 (17)	36 (13)** 76 (20)	30 (13)** 57 (17)	25 (10)** 55 (16)	—
Same, but all fingers press on one bar	—	digits 2, 3, 4, 5 combined: 162 (33)				
Tip force (as in typing; angle between distal and proximal phalanges about 135 degrees)	— 65 (12)	30 (12)** 69 (22)	29 (11)** 50 (11)	23 (9)** 46 (14)	19 (7)**	—
Palm touch (Coupling #2) perpendicular to palm (arm, hand, digits extended and horizontal)	—	—	—	—	—	233 (65)
Hook force exerted with digit tip pad (Coupling #3, "scratch")	61 (21) 118 (24)	49 (17) 89 (29)	48 (19) 104 (26)	38 (13) 77 (21)	34 (10) 66 (17)	108 (39)** 252 (63)
			all digits combined:			
Thumb–fingertip grip (Coupling #4, "tip pinch")	—	1 on 2 50 (14)** 59 (15)	1 on 3 53 (14)** 63 (16)	1 on 4 38 (7)** 44 (12)	1 on 5 28 (7)** 30 (6)	—
Thumb–finger palmar grip (Coupling #5,1 on "pad pinch")	2 and 3 85 (16)** 95 (19)	1 on 2 63 (12)** 34 (7)	1 on 3 61 (16)** 70 (15)	1 on 4 41 (12)** 54 (15)	1 on 5 31 (9)** 34 (7)	—
Thumb–forefinger side grip (Coupling #6, "side pinch")	—	1 on 2 98 (13)** 112 (16)	—	—	—	—
Power grasp (Coupling #10, "grip strength")	—	—	—	—	—	318 (61)** 366 (53)

* Means and standard deviations in *N*.

** Students' results; all others are machinists' results.

(Adapted from Kroemer, Kroemer, Kroemer-Elbert, *Ergonomics: How to Design for Ease and Efficiency.* Englewood Cliffs, NJ: Prentice Hall, 1994. Used with permission by the publisher. All rights reserved.)

- ➢ Keep the shoulder relaxed, the elbow at the side of the body, the forearm semipronated, and the wrist straight.
- ➢ Use tools with handles of appropriate size and shape, as already discussed.
- ➢ Round off all edges and sharp corners on the hand tool or at the workstation with which the worker might come in contact.
- ➢ Avoid excessive cooling of the hand, either by a cold environment or by strong air movement (particularly important with air-powered tools) or by contact with metal handles that easily conduct heat energy away from the hand.
- ➢ Ensure that gloves worn actually help the activity but do not hinder motion or enforce awkward wrist positions.

Table 13–P. *Average Forces* Exerted by Nine Subjects in Fore, Aft, and Down Directions with the Fingertips, Depending on Angle of the Proximal Intraphalangeal (PIP) Joint*

	PIP Joint at 30 Degrees			*PIP Joint at 60 Degrees*		
	Fore	*Aft*	*Down*	*Fore*	*Aft*	*Down*
DIGIT						
2 Index	5.4 (2.0)	5.5 (2.2)	27.4 (13.0)	5.2 (2.4)	6.8 (2.8)	24.4 (13.6)
2 Nonpreferred hand	4.8 (2.2)	6.1 (2.2)	21.7 (11.7)	5.6 (2.9)	5.3 (2.1)	25.1 (13.7)
3 Middle	4.8 (2.5)	5.4 (2.4)	24.0 (12.6)	4.2 (1.9)	6.5 (2.2)	21.3 (10.9)
4 Ring	4.3 (2.4)	5.2 (2.0)	19.1 (10.4)	3.7 (1.7)	5.2 (1.9)	19.5 (10.9)
5 Little	4.8 (1.9)	4.1 (1.6)	15.1 (8.0)	3.5 (1.6)	3.5 (2.2)	15.5 (8.5)

* Average forces and standard deviations, in *N*.

Adapted from Kroemer, Kroemer, Kroemer-Elbert, *Ergonomics: How to Design for Ease and Efficiency*. Englewood Cliffs, NJ: Prentice Hall, 1994. Used with permission by the publisher. All rights reserved.

➢ Minimize vibrations of hand tools to avert cumulative trauma disorders—covered later in this chapter.

WORKSTATION DESIGN

The goal in designing a workstation is to promote ease and efficiency for the working person. Productivity will suffer in quantity and quality if the operator is uncomfortable, if the layout of the workstation or the job procedures are awkward. Conversely, productivity will be enhanced if the operator is comfortable physiologically and psychologically and if the layout of the workstation is conducive to performing the task well. Keeping this in mind, try to establish an ideal workstation, task, and work environment first and to make concessions to practical limitations only if absolutely necessary.

General Principles

Five general rules govern the design of workplaces:

1. Plan the ideal, then the practical.
2. Plan the whole, then the detail.
3. Plan the work process and the equipment to fit the human.
4. Plan the workplace layout around the process and the equipment.
5. Use mockups to evaluate alternative solutions and to check the final design.

In this design process, the following aspects are of primary importance:

➢ *Space:* clearance for the operator's body entrance and egress (including emergency exit); suitable body movements and postures at work; operation of controls and equipment (without bumping elbows, knees, or head);

➢ *Manipulation:* operation of tools, controls, and work pieces by hand (or foot) including seat adjustment; avoidance of excessive forces or inadvertent operation of controls; use of emergency items (stop button, flashlight, survival equipment);

➢ *Seeing:* visual field and information both inside (displays and control settings) and outside (road, machine being controlled); visual contact with co-workers; lighting (illumination, luminance, shadows; avoid glare).

➢ *Hearing:* auditory information, such as oral communication with other workers, signals (including warning signals), and sounds from equipment (engine underload, cutting tool).

More detailed design guidelines depend on the special workstation, on the specific work task, and on the environment. Such guidelines can be found, for example, in books by Cushman and Rosenberg (1991); Eastman Kodak Company (1983, 1986); Fraser (1989); Konz and Johnson (1999); Karwowski and Marras (1999); Kroemer et al (2001) Salvendy (1997); and Woodson et al (1991). *Military Standards 759* and *1472* also provide a wealth of human engineering information.

Standing or Sitting

Whether the operator should stand or sit at the workstation depends on several factors: the mobility required, the forces needed, the size of the work piece, and the required precision. The advantages of standing over sitting include more mobility, more body strength available, less front-to-rear room required, no seat needed, and greater latitude in workstation design. The advantages of sitting are that pedals can be operated with the foot more effectively (more strongly, and with more precision), it is less fatiguing to maintain the sitting posture (if a good seat is available), and manipulation and vision may be more precise. Unless the specific work task or the environment or conditions strictly demand either sitting or standing, provisions should be made to allow the operator to sit or stand at will. Figure 13–17 shows "stand-seats," which can offer a useful compromise. (More information on seat design is contained in the section on computer workstations of this chapter.)

WORKPLACE DESIGN

The most basic requirement for a workplace is that it must accommodate the person working in it. Specifically, this means that the workspace for the hands should be between hip and chest height in front of the body. Within this region, the lower locations are preferred for heavy manual work, and the higher locations are suitable for tasks that require close visual observation. Contours of reach envelopes indicate the maximum distances at which objectives can be manipulated or placed. Figure 13–18 shows an example of such reach capabilities.

Work objects should be located close to the front edge of the work surface so that the worker does not have to bend over and lean across the surface to grasp items. To allow the person to be close to the front edge of the work surface, sufficient room must be provided so that thighs, knees, and toes can be placed somewhat under the work surface if the work is performed while standing. For sitting operators, deeper and wider leg room must be provided under the bench, table, or desk. If foot controls are used, additional room for foot and leg motions may be needed. Pedals that must be operated continuously or frequently normally require a seated operator because if a person operated them while standing, the body weight would have to be supported on one foot.

Visual displays including instruments, counters, dials, and signal lights are preferably placed in front of the body and below eye level so that the line of sight (which runs from the eyes to the visual target) is declined 10 degrees to 40 degrees below the horizontal level. Table 13–Q lists general principles for workstation design; specifics for computer workstations follow later in this chapter.

Work-Space Dimensions

Work-space dimensions can be grouped into three basic categories: minimal, maximal, and adjustable dimensions. *Minimal* work-space dimensions provide clearance for the worker. Many minimal clearance dimensions, such as the open leg space under a work table, can be determined using large percentile values from anthropometric tables (see

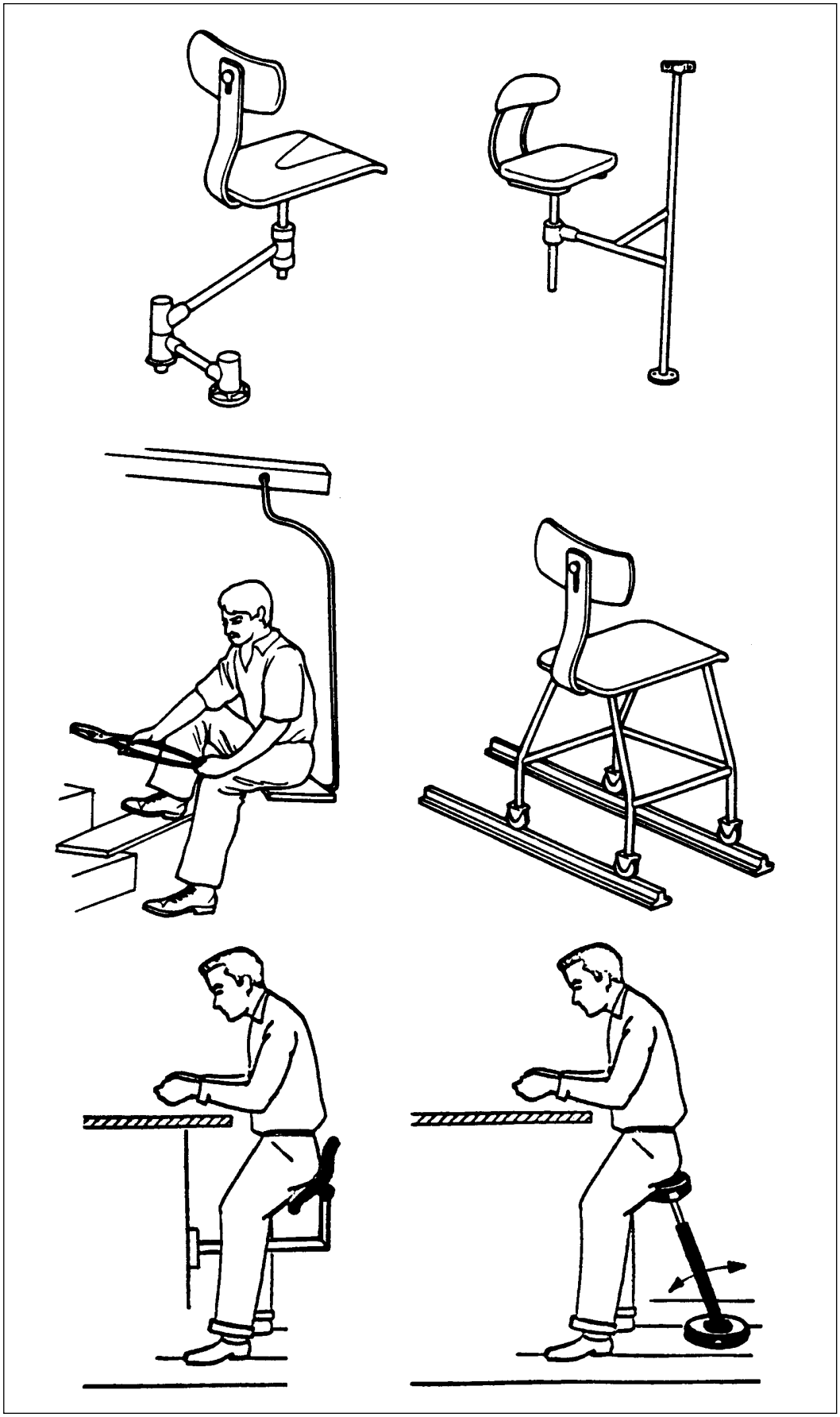

Figure 13–17. Examples of stand-seats. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency.* Upper Saddle River, NJ: Prentice-Hall. With permission by the publisher. All rights reserved.

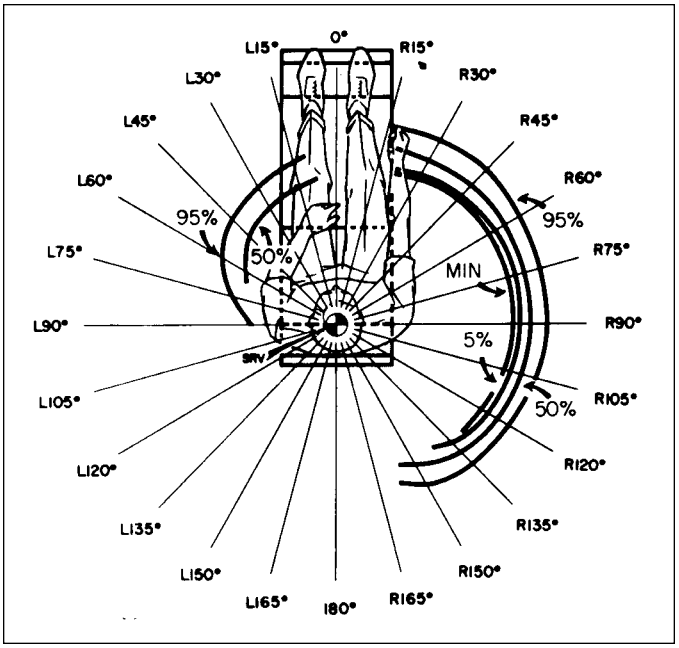

Figure 13–18. Grasping reach contours of the right hand in a horizontal plane 25 centimeters above the seat reference point. (Reprinted with permission from Damon, Stoudt, and McFarland, *Human Body in Equipment Design*, 1966.)

Table 13–E). For example, if a 95th-percentile knee height were used to determine the height of the legroom, nearly everybody's legs would fit under the table. Even larger values need to be considered for other clearances: if the opening of a doorframe were at the 95th-percentile value, at least five percent of all users would bump their heads. *Maximal* dimensions are selected to permit smaller workers to use the equipment; for example in terms of the distance at which one can reach. A related case is setting force requirements so low that even a weak person can operate the equipment. Often, the fifth percentile value of the relevant body attribute is used for determining minimal design measurements.

Adjustability permits the operator to modify the work environment and equipment so that it conforms to that individual's particular set of physical (anthropometric, biomechanical) characteristics as well as to subjective preferences. A six-way adjustable seat in a truck is an example of the proper adjustability that accommodates individual operators. Adjustable dimensions are particularly important when optimal performance with minimum effort is necessary to accomplish the work task.

The requirements for an industrial work seat are essentially the same as those for an office chair (see the following section in this chapter on computer workplaces). However, the industrial work seat is probably somewhat more rugged and has soil-resistant upholstery. As shown in Figure 13–19,

Table 13–Q. ***Ergonomic Guidelines for Workplace Design***

1. In the design of the facility, assure a proper match between the facility and the operator to avoid static efforts, such as holding a work piece or hand tool. Static (isometric) muscle tension is inefficient and leads to rapid fatigue.
2. The design of the task and the design of the workplace are interrelated. The work system should be designed to prevent overloading the muscular system. Forces necessary for dynamic activities should be kept to less than 30% of the maximal forces the muscles are capable of generating. Occasionally, forces of up to 50% are acceptable when maintained for only short durations (approximately 5 minutes or less). If static effort is unavoidable, the muscular load should be kept quite low—less than 15% of the maximal muscle force.
3. Aim for the best mechanical advantage in the design of the task. Use postures for the limbs and body that provide the best lever arms for the muscles used. This avoids muscle overload.
4. Foot controls can be used by the seated operator. They are not recommended for continuous use by a standing operator because of the imbalanced posture imposed on the operator. If a pedal must be used by the standing operator, it should be operable with either foot. Avoid hard floors for the standing operator; a soft floor mat is recommended, if feasible.
5. Maintain a proper sitting height, which is usually achieved when the thighs are about horizontal, the lower legs vertical, and the feet flat on the floor. Use adjustable chairs and, if needed, footrests. When adjusting the chair, make sure that:
   a. elbows are at proper height in relation to work surface height;
   b. the footrest is adjusted to prevent pressure at undersides of the thighs;
   c. the backrest is large enough to be leaned against, at least for a break, and
   d. special seating devices are used if the task warrants them.
6. Permit change of posture—static posture causes problems in tissue compression, nerve irritation, and circulation. The operator should be able to change his or her posture frequently to avoid fatigue. Ideally, the operator should be able to alternate between sitting and standing; therefore, a workplace that can be used by either a sitting or standing operator is recommended.
7. In designing the facility, accommodate the large operator first and give that operator enough space. Then provide adjustments and support so that the smaller operator fits into the work space. For standing work, the work surface should be designed to accommodate the taller operator; use platforms to elevate shorter operators. (But watch out for stumbles and falls!) For reach, design to accommodate the shorter operator.
8. Instruct and train the operator to use good working postures whether sitting or standing, working with machines and tools, lifting or loading, or pushing or pulling loads.

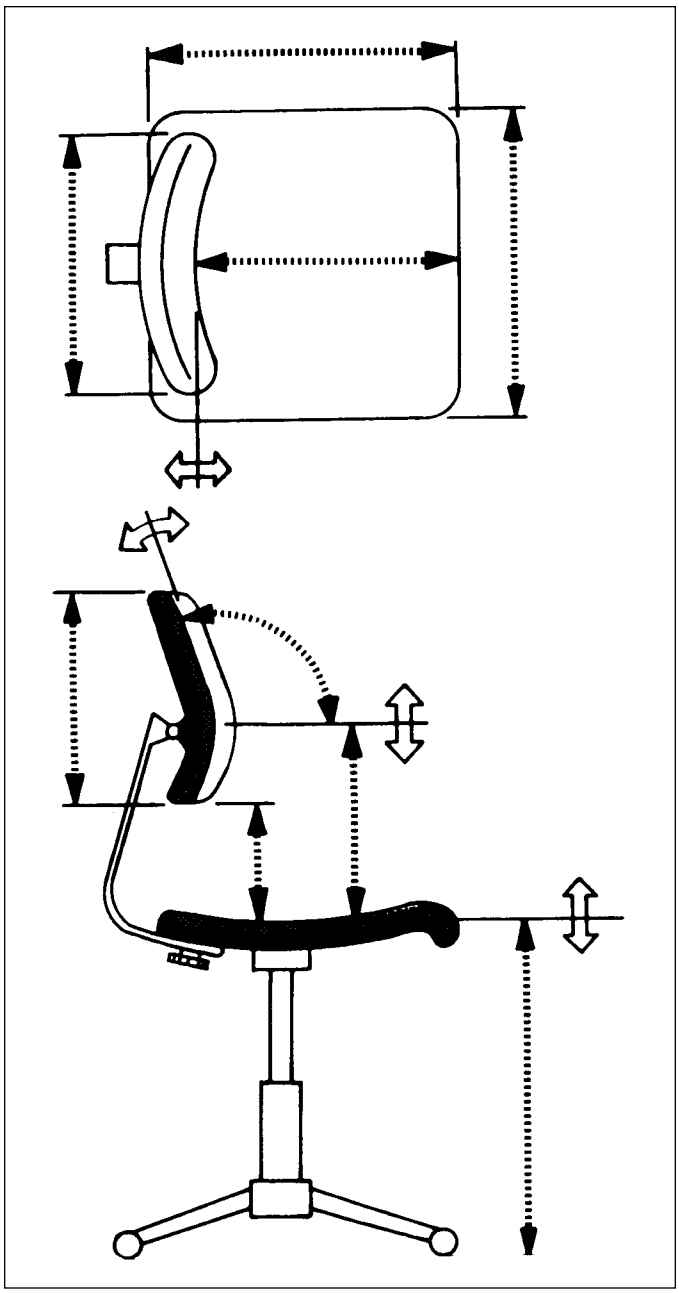

Figure 13–19. Main design features of an industrial work seat. (Reprinted with permission from the American Industrial Hygiene Association.)

the industrial work seat should be adjustable in seat pan height between about 38 and 51cm (15–20 in.). Its front edge should be well rounded to avoid pressure to the underside of the thighs. A backrest should be provided, if the work activities allow it. The backrest should be adjustable in height and in distance from the front edge of the seat pan. To allow free mobility of the arms and shoulder blades, the backrest probably should not extend up to the neck (as the office chair may); however, a large backrest allows relaxing during a break from the work activities. The backrest should have a protrusion or pad at lumbar height, just like an office chair.

Objects that must be seen and observed (displays, signal lights, controls, dials, keyboards, written documents) should be placed well within the worker's visual field. This is the area, described in degrees, in which form and color of objects can be seen by both fixated eyes. The more important visual targets, especially those that must be read exactly, should be placed in the center of the preferred viewing area. To determine this preferred visual field, one first establishes a reference line, the Ear-Eye line, which runs—seen on the side of the head—through the ear and the juncture of the eyelids, as shown in Figure 13–20. (The Ear-Eye is much more easily established than the Frankfurt line, often used in older texts; for more information, see Kroemer et al, 2001.) When the angle between the horizon and the Ear-Eye line, P in Figure 13–20, is about 15 degrees, the head is held erect on an upright neck and trunk. Looking at an object in the distance, the preferred line of sight is approximately horizontal, i.e., about 15 degrees below the Ear-Eye line. But for focussing at close targets, such as when reading a text either printed or displayed on a computer screen, most people prefer to look down steeply, as much as 60 degrees below the Ear-Eye line.

OFFICE (COMPUTER) WORKSTATIONS

Complaints related to posture (musculoskeletal pain and discomfort) and vision (eye strain and fatigue) are, by far, the most frequent health problems voiced by computer operators in North America and Europe. Apparently, some of these complaints are related. Difficulties in viewing (focusing distance, angle of the line of sight, glare), together with straining curvatures of the spinal column, particularly in the neck and lumbar regions, if joined by fatiguing postures of shoulders and arms result in a stress-strain combination in which causes and effects intermix, alternate, and build on each other, especially if socio-psychological conditions are faulty (Carayon, Smith, & Haims 1999).

Improperly designed workstations, ill-selected furniture, and poorly arranged equipment are the principal causes of postural problems. The questionable design idol of "sitting upright" at the old office desk has been carried over to the computer workplaces. Even the 1988 ANSI 100 standard on visual display terminal workstations used an "upright, or near straight" posture for deriving furniture dimensions. In reality, many other working postures exist that are suitable for the work, and subjectively comfortable. Current design strategies recognize and build upon the great variety of individually preferred body movements and work postures in the computerized office (Kroemer and Kroemer 2001).

Successful ergonomic design of the office workstation depends on proper consideration of several interrelated aspects, sketched in Figure 13–21. The postures that a person assumes and the ways to perform activities are strongly influenced by

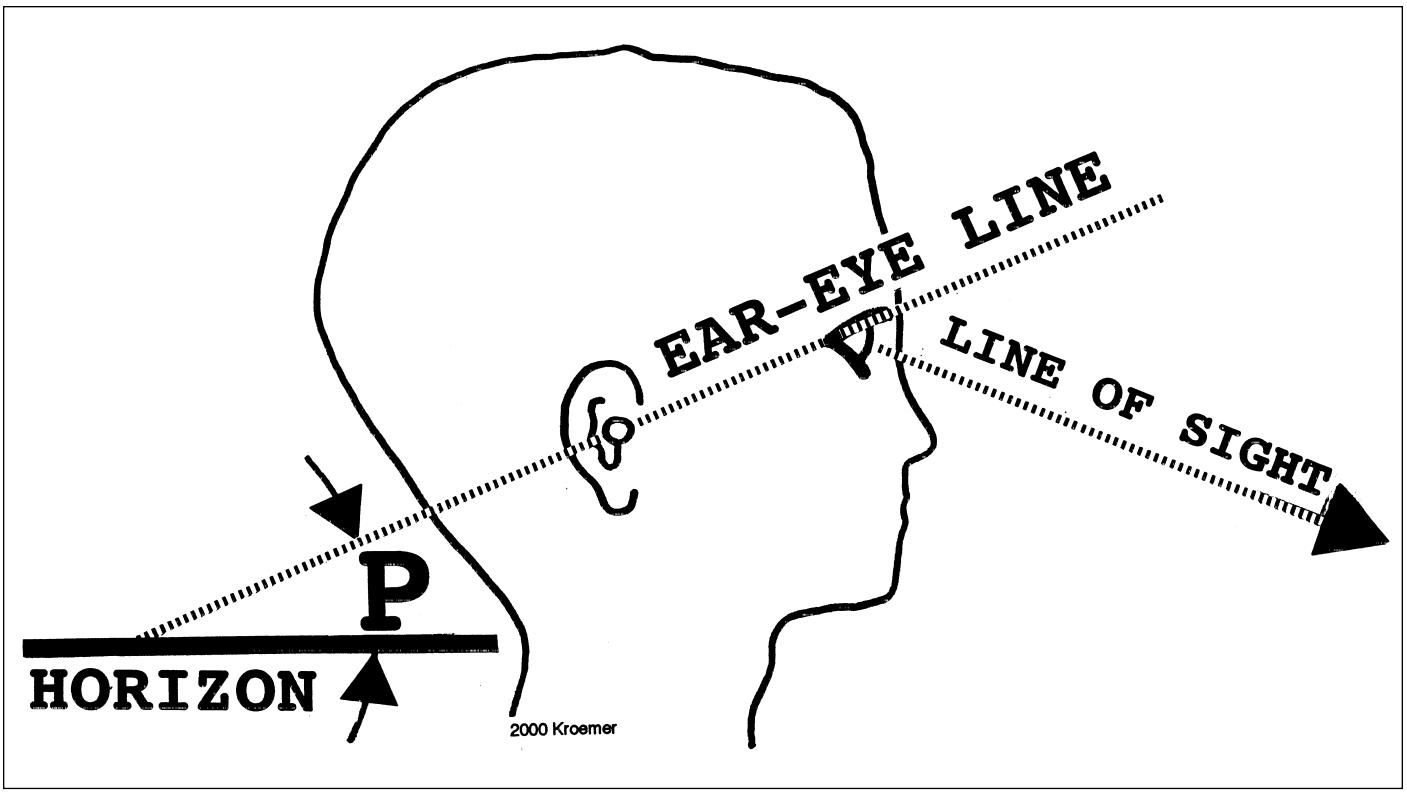

Figure 13–20. Ear-eye line and the line of sight

workstation conditions including furniture, equipment, and environment. All must "fit" the person and the task.

The actual work postures and motions affect physical and psychological well being, while the work activities determine the output of the person working with the equipment. Feeling well, both physically and about one's performance, affects health, work attitudes, and work output. Of course, the interpersonal and organizational "climate" is a major factor also. These interactive relationships are not static but vary with time, and they are somewhat different from person to person.

This brief discussion of the many and multileveled relationships among work variables is meant to emphasize the need for carefully designing the workstation—particularly its furniture, equipment, and lighting—so that the desired results of well-being and high performance are achieved.

Work Task

Within about a decade, the use of computers has profoundly changed many tasks in the office, in the company building or at home. Most "typing" is now performed on a computer rather than with a traditional typewriter. This allows the operator to control the layout of texts and graphics while it eliminated the frustrating and time-consuming job of retyping large chunks of material to incorporate relatively minor changes.

Compared to a typist's job, word processing affords more control functions and detail responsibilities, and it requires different and more complex skills. Working with a computer establishes special demands on the operator's visual and motor capabilities. The eyes have three important tasks:

1. to search for specific keys (the exorbitant number of keys on most computer keyboards requires visual search and identification; "blind" touch typing is seldom possible)
2. to read a source document (for input into the computer)
3. to scan the display of the monitor (either to obtain new information or to receive feedback about the material already transmitted to the computer system)

The fingers input information to the system via keyboard, mouse, trackball, and other controls, such as light pen and touch panel. Voice communication with the computer, both as input and output, is being developed.

Positioning the Body in Relation to the Computer

With today's state of the art, the operator interfaces with the computer mostly through eyes and fingertips. The ears are input channels to the operator, and the mouth is a natural output device. However, sound and speech are not often used to communicate with computers even though these signals can travel through the air or can be transmitted through speaker phones attached to the head. Use of acoustic signals would not restrict the operator's head position and hence, the posture of the whole body. However, with current technology, the operator receives primary input through the eyes, as they focus their sight on the monitor, on the source document, and on the keys. Thus, the position of the person's eyes is rather immovable with

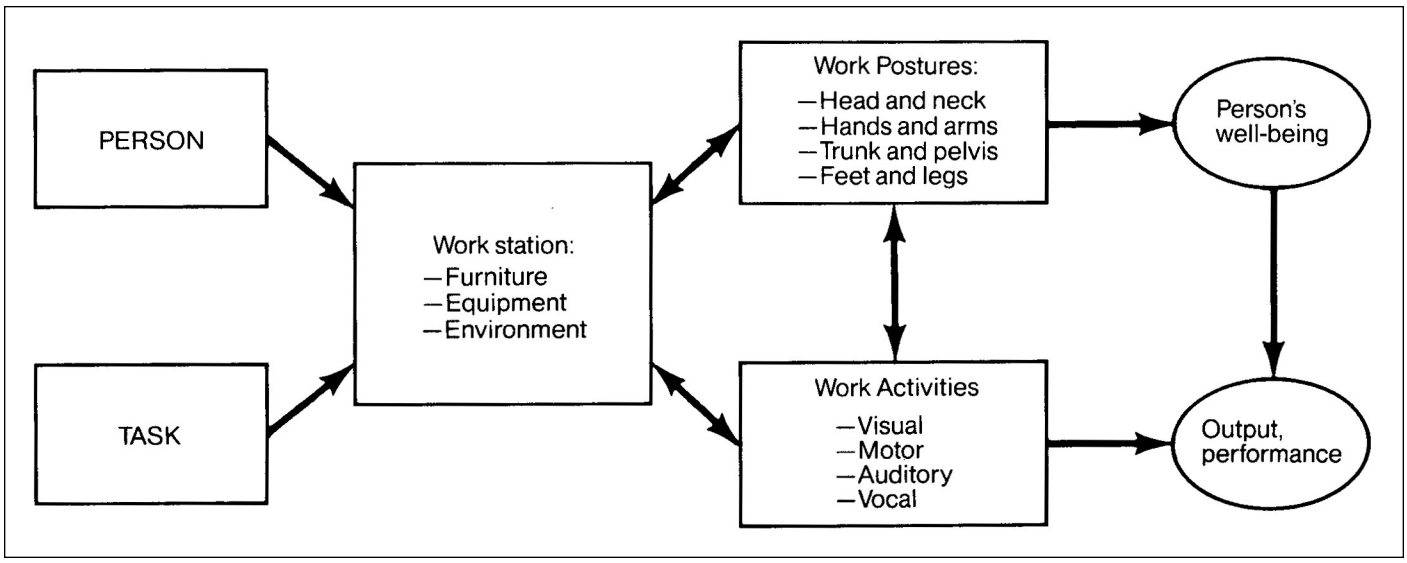

Figure 13–21. Interactions among workstation design, work postures, and work activities and their effect on the computer operator's well being and performance.

respect to the visual target. This eye fixation has the consequence that head, neck, and hence, trunk cannot be moved much but must remain in place, making for a rigid body posture at work.

Instead of voice, the digits of the hands are the user's major output links to the computer, just as they are with the old-fashioned typewriter. As keys, mouse pad, trackball, or touch panel are fixed within the workstation, the operator has no choice but to keep the hands on them. This often determines, in fact, fixates, the person's body posture, even more so if foot controls are in use.

Healthy Work Postures?

In the 1880s, it was generally believed that an "upright" trunk, as when standing still and erect, was part of a healthy posture (Staffel 1884, 1889). For about 100 years, this idea had been used—usually with presuming right angles at hips, knees and ankles—to design office chairs and other furniture. However, contrary to what we have been taught, today there are no compelling physiological or orthopedic reasons to make people stand or sit "straight." Nothing is wrong with this posture when it is freely chosen, but, if left alone, few people choose and maintain this posture over extended periods of time.

An upright trunk has a straight spinal column on the frontal or posterior view but, in the lateral view, the spine forms one forward bend (lordosis) each in the neck and in the low-back region, and a slight rearward bulge (kyphosis) in the chest region. This, sitting (or standing) upright, does not mean that the spinal column is ramrod straight.

For nearly a century, physicians, orthopedists, physical therapists, parents, teachers, and military officers advocated the 19th-century "normal" posture of erect standing, as recommended by Staffel and his contemporaries. Even today, that upright standing posture is commonly considered "good and proper." But it is certainly impractical for working since we do move about—and should do so—instead of standing (or sitting) stiff and still. Maintaining any body position becomes unpleasant after a while: even while we rest in bed, or relax in our most comfy easy chair, we humans must move our bodies and reposition ourselves after some time.

In recent years, the term *neutral posture* has become popular. It suggests a healthy, desirable, or central position of body members. What does neutral mean? Is that the middle of the total motion range in a joint? This would make some sense for the wrist, indicating the hand is straight, i.e., in line with the forearm. But there is no obvious significance to the middle joint position in elbow or knee, shoulder or hip, or the spinal column. Does the term "neutral" suggest that all tissue tensions about a joint are balanced, so that the position is stable? Does the term infer a minimal sum of tissue tensions (torques) around a body joint? Or does this apply to tensions about several joints, or all body joints? Does "neutral" imply minimal joint discomfort? Does it infer a relaxed posture? Or a posture instinctively assumed for a task, to generate high body strength, or to avoid fatigue?

The simplistic concept that sitting upright, with thighs horizontal and lower legs vertical, is "sitting healthily" endured for a surprisingly long time. Even today, that upright posture with slight lordoses (forward bends) in the lumbar and cervical spine areas and a light kyphosis (backward bend) in the thoracic spine is stereotypically considered healthy, balanced, or neutral (Merrill, 1995). Obviously, this posture can be quite appropriate for a while, but it is erroneous to use it as the overriding guiding principle for the design of the chair or other workstation furniture. To simply design for this postural idol completely disregards that it is healthy to change among various postures while sitting, not to stay in any one position for too long.

Figure 13–22. Moving, not sitting still, at work.

FREE-FLOWING MOTION

In 1984, Grandjean, Huenting, and Nishiyama found that persons sitting in offices did not sit upright but leaned backward even if their chairs apparently were not designed for such a posture. Bendix et al (1996) reported that persons, while reading, often assumed a kyphotic lumbar curve even when sitting on a chair with a lumbar pad that should have produced a lordosis. These finding support the everyday observation that people sit any way they want, regardless of how experts think they should sit!

Allowing persons freely to select their posture has led in two instances to surprisingly similar results. In 1962, Lehmann showed the contours of five persons "resting" under water where the water fully supports the body. Sixteen years later, NASA astronauts were observed when they relaxed in space. The similarity between the postures under water and in space is remarkable. One might assume that, in both cases, the sum of all tissue torques around body joints has been nulled. Apparently not incidentally, the shape of so-called easy chairs is quite similar to the contours of the relaxed body.

Dynamics is a label than can be applied to current design of office chairs, as opposed to the "statics" of maintained posture. People do move about as they please. Design should encourage and support free-flowing motions, as sketched in Figure 13–22, with halts for temporary postures at personal whim.

The *free-flowing motion* design idea has these basic tenets:

- ➢ Allow the user to freely move in and with the chair and to halt at will in a variety of sitting postures, each of which is supported by the chair; and to get up and move about.
- ➢ Make it easy for the user to adjust the chair and other furniture, especially keyboard and display, to the changing motions and postures.
- ➢ Design for a variety of user sizes and user preferences.
- ➢ Consider that new technologies develop quickly and should be usable at the workstation. For example, radically

new keyboards and input devices, including voice recognition, may be available soon; display technologies and display placement are undergoing rapid changes; laptop and heldheld computers with small key sets and attached screens are widely used.

Designing for Vision, Manipulation, and Body Support

It is helpful for the layout of a work task and workstation to think of three main links between a person and the task.

- ➢ The first link is the *visual interface*. One must look at the keyboard, the computer screen, or the printed output, and source documents.
- ➢ The second link is *manipulation*. The hands operate keys, a mouse, or other input devices; manipulate pen, paper, and telephone. Occasionally, the feet operate controls, for example, starting and stopping a dictation machine. The intensities of the visual and motor requirements depend on the specific job.
- ➢ The third link is *body support*. The seat pan supports the body at the undersides of the thighs and buttocks, and the backrest supports the back. Armrests or a wrist rest may be other support links.

DESIGNING FOR VISION

The location of the visual targets greatly affects the body position of the computer operator. Many studies have shown what is intuitively apparent: objects upon which we focus our eyesight should be located directly in front, at a convenient distance and height from the eyes. If one is forced to turn the head to the side or tilt it up to view the computer screen or the document, he or she will often experience *eyestrain*. Eyestrain is often accompanied by pain in neck, shoulders, and back. Yet, two basic mistakes are often made in many workstations: the monitor is set up much too far and too high and source documents are often laid flat to the side. In either case, the operator must crane his or her neck.

Monitor Support. It is advantageous to use a separate support for a separate computer monitor so that the display can be adjusted in height independently from keyboard, work surface, and table or desk. Easy adjustment is facilitated if the surface can be moved up or down easily, such as by a hand crank or an electric motor.

The common practice of putting the monitor on the CPU box, and possibly also on an stem for angle adjustment, lifts the screen much too high for most users, who consequently tilt their heads back and then may suffer from neck and back problems. Instead, the monitor should be located low behind the keyboard so that one looks down at it.

As a rule, the screen or source document should be about half a meter from the eyes, at the proper viewing distance for the operator's eyes. This is the distance for which corrective eye lenses are usually ground.

Document holder. If one reads from a source document often, one should use a document holder that holds the document close and parallel to the monitor screen, about perpendicular to the line of sight. A document placed far to one side causes a twisted body posture and lateral eye, head, and neck movements.

Proper lighting. The computer office should be illuminated at about 200 to 500 lx with today's self-lit displays. Paper documents may be difficult to read at this fairly low level, so one might want to shine a special task light on them—making sure that this does not create glare. For offices without computers, the proper illumination range is from 500 to 1,000 lx, even more if there are many dark (light-absorbing) surfaces present.

DESIGNING FOR MANIPULATION

In addition to the eyes, our hands are usually very busy doing various office tasks: grasping and moving papers, taking notes, dialing phone numbers, and using various computer input devices. If our hands do many different activities, the varied manipulation is likely to keep our arms and the upper body moving around in our workspace. Motion is desirable—in contrast to maintaining a fixed posture, such as when tapping the keyboard over an extended time.

Keyboards and other computer input gadgets should all be placed directly in front of the body, at about elbow height when the shoulders are relaxed and the upper arms hang by the sides of the upper body. A keyboard set up higher forces one to lift the arms and shoulders, requiring unnecessary muscle tension. Placing the keyboard and mouse at different levels, to the side, or too far away will cause muscle tension in the back, neck, and arms to get and hold the hands there. This often leads to irritation and pain, and occasionally to overuse disorders such as bursitis, tendinitis, or cervicobrachial syndrome. These and other overuse disorders are discussed later in this chapter.

Resting one's wrist or arm on a hard surface or, worse, on a hard edge often occurs when a working surface is pushed up too high, above the operator's elbow height. This leads to sharp local pressure at the point of contact that can cause painful reactions. Examples are cubital tunnel syndrome, when the cubital nerve is compressed by placing the elbow on a hard surface, or carpal tunnel syndrome, when a sharp edge (for example, of a keyboard housing) presses into the wrist and palm area of the hand. These conditions can be avoided by placing the manipulation area low, by softening surfaces that support the arm and hand (rounding edges, padding surfaces, giving wrist supports), and by proper working habits.

DESIGNING FOR MOTION

The human body is built to move about, not to hold still. It is uncomfortable and tiresome to maintain a body position without change over extended periods. While driving a car, a

driver must hold his or her head in much the same position in order to see the road and instruments, and keep hands and foot fixed on wheel and pedal. After a while, it becomes very difficult to stay in the same seated position and posture, even though the nearly immobile posture is supported by a relatively comfortable seat. A similar situation arises often at computer workstations—where the chair is often much less suitable than the car seat. But, unlike when driving, in the office one can get up and move around at will—a good habit!

At work, the body needs to move to not keep a static posture. Therefore, the primary aim of ergonomic workstation design is to facilitate body movement, not to support maintenance of certain body positions. A convenient way to do so is for the designer to consider the extreme body postures expected to occur and to lay out the workspace for motion between these. In the computerized office this means to design for walking (standing) and for sitting. The seat should be designed for relaxed and upright sitting, for leaning backward and forward, and for getting in and out.

Several chair designs have gone beyond the concept of a user-adjustment. They incorporate seat pans and backrests that follow the motions of the sitting person and provide support throughout the range. Other designs flow from the thought that the seat must not be a passive device but an active one: The chair as a whole, its pan, or backrest, can automatically change the configuration slightly over time, perhaps in response to certain sitting postures maintained by the person. The change can be in angles, or in stiffness of the material. Seat and back cushions that pulsate were tried in the 1950s to alleviate the strain that military aircrews felt when they had to sit for hours on end to fly extended missions. An "intelligent seat" can remind the user to move, or to get up, after sitting in a static position for some period of time.

COMFORT VERSUS DISCOMFORT?

Comfort (as related to sitting) has long been defined, simply and conveniently, as the absence of discomfort. However, the underlying concept is false: in 1997 Helander and Zhang showed that, in reality, these two aspects are not the opposite extremes of one single-judgment scale. Instead, there are two scales, one for the agreeable feelings of "comfort" and the other for such unpleasant experiences as not being at ease, fatiguing, straining, smarting, hurting. All are terms that indicate some degree of discomfort. These two scales partly overlap but are not parallel.

Using the term *annoyance* (instead of discomfort as the descriptive label for the scale containing the unpleasant statements) helps to avoid the false concept of one scale that has comfort and discomfort as opposites. The other scale, containing the agreeable statements, is labeled with the term *comfort*, as has been the convention.

The Annoyance Scale

Feelings of annoyance (formerly described as discomfort) are expressed by such words as stiff, strained, cramped, tingling, numbness, not supported, fatiguing, restless, soreness, hurting, and pain. Some of these attributes can be explained in terms of circulatory, metabolic, or mechanical events in the body; others go beyond such physiological and biomechanical phenomena.

Users can rather easily describe design features that result in feelings of annoyance such as chairs in wrong sizes, too high or too low, with hard surfaces or edges; but avoiding these mistakes does not, per se, make a chair comfortable.

The Comfort Scale

Feelings of comfort when sitting are associated with such descriptive words as warm, soft, plush, spacious, supported, safe, pleased, relaxed, and restful. However, exactly what feels comfortable depends very much on the individual and his or her habits, on environment and task, and on the passage of time.

Esthetics plays a role. If we like the appearance, the color, the ambience, we are inclined to feel comfortable. Appealing upholstery, for example, especially when it is neither too soft nor too stiff but distributes body pressure along the contact area, and "breathes" by letting heat and humidity escape as it supports the body, can contribute to the feeling of comfort.

Ranking Chairs by Annoyance or Comfort

Helander and Zhang used six specific statements about chair annoyance or comfort (each with nine steps from "not at all" to extremely") followed by one general statement.

The statements for annoyance are as follows:

1. I have sore muscles.
2. I have heavy legs.
3. I feel uneven pressure.
4. I feel stiff.
5. I feel restless.
6. I feel tired.
7. *I feel annoyed.*

The following statements characterize comfort:

1. I feel relaxed.
2. I feel refreshed.
3. The chair feels soft.
4. The chair is spacious.
5. The chair looks nice.
6. I like the chair.
7. *I feel comfortable.*

Helander and Zhang's subjects said it was easy to rank chairs in terms of overall comfort or annoyance (answer 7 in the lists) after having responded to the preceding, more detailed descriptors.

The researchers concluded that it is apparently more difficult to rank chairs, unless truly unsuitable, by attributes of annoyance (as opposed to comfort) because the body is surprisingly adaptive (except when the sitter has a bad back). In contrast, comfort descriptors proved to be sensitive and discriminating for ranking chairs in terms of preference.

Preference rankings of chairs could be established early during the sitting trials; they did not change much with sitting duration. Still, it is not clear whether a few minutes of sitting on chairs are sufficient to assess them, or whether it takes longer trial periods.

Designing the Sit-Down Workstation

One of the first steps in designing the office workstation for seated persons is to establish the main clearance and external dimensions. The size of the furniture derives essentially from the body dimensions and work tasks of the people in the office. Main vertical anthropometric inputs to determine the height requirements are lower leg (popliteal and knee) heights, thigh thickness, and the heights of elbow, shoulder, and eye—all listed in Table 13–E for North Americans.

The common design procedure is to start from the floor: upon it one stacks the height of the chair, then the height of supports for input devices (such as the keyboard, mouse pad, etc.), finally the height of table and desk surfaces. To truly fit all the sizes and preferences of everyone in the office, all the furniture heights should be widely and easily adjustable.

Another furniture design strategy starts with the premise of a fixed height of the major work surface (the desk or table in traditional offices), with adjustable heights of the seat and of the computer support. This regularly requires narrower height adjustment ranges for seat and equipment, but smaller persons need footrests. Another design approach relies on the same seat height for all, which results in the smallest adjustment needs for desks, tables, and supports, yet all but the most long-legged individual need footrests (Kroemer et al, 2001). The depths and widths of the furniture must fit the horizontal body dimensions (especially popliteal and knee depths, hip breadth and reach capabilities) as well as work task and equipment space needs.

The furniture at the computer workstation consists primarily of the seat, the support for the data-entry device, the support for the display, and a working surface (table or desk). It is best, and most expensive, to have all of these independently adjustable. These ranges should make the office furniture fit practically everybody in Europe or North America, tall or short. Of course, if the workplace is used by just one person, such as in the case of a personal home office, then only that one user must be fitted and little or no subsequent adjustments may be necessary.

THE OFFICE CHAIR

As discussed earlier, "proper sitting" at work was long believed to mean an upright trunk, with the thighs (and forearms) in essence horizontal and the lower legs (and upper arms) vertical. This model, with all major body joints at zero, 90, or 180 degrees makes for a convenient but misguiding design template: the "0-90-180 posture" is neither commonly employed nor subjectively preferred, and it is not even especially healthy. To suit the seated person, the designer of office furniture, especially of chairs, has to consider a full range of motions and postures, as discussed by Kroemer and Kroemer (2001).

Seat Pan

When one sits down on a hard flat surface, not using a backrest, the *ischial tuberosities* (the inferior protuberances of the pelvic bones) act as fulcra around which the pelvic girdle rotates under the weight of the upper body. Since the bones of the pelvic girdle are linked by connective tissue to the lower spine, rotation of the pelvis affects the posture of the lower spinal column, particularly in the lumbar region. If the pelvis rotation is rearward, the normal lordosis of the lumbar spine is flattened.

Leg muscles (hamstrings, quadriceps, rectus femoris, sartorius, tensor fasciae latae, psoas major) run from the pelvis area across the hip and the knee joints to the lower legs. Therefore, the angles at hip and knee affect the location of the pelvis and hence the curvature of the lumbar spine. With a wide-open hip angle, a forward rotation of the pelvis on the ischial tuberosities is likely, accompanied by lumbar lordosis. (These actions on the lumbar spine take place if associated muscles are relaxed; muscle activities or changes in trunk tilt can counter the effects.)

Accordingly, in 1884 Staffel proposed a forward-declining seat surface to open up the hip angle and bring about lordosis in the lumbar area. In the 1960s, a seat-pan design with an elevated rear edge became popular in Europe. Since then, Mandal (1975, 1982) and Congleton et al (1985) again promoted that the whole seat surface slope fore-downward. To prevent the buttocks from sliding down on the forward-declined seat, the seat surface may be shaped to fit the human underside (Congleton et al), or one may counteract the downward-forward thrust either by bearing down on the feet (Mandal) or by propping the upper shins on special pads. A seat surface that can be tilted throughout the full range (from declined forward, kept flat, to inclined backward) naturally allows one to assume various curvatures of the lower spinal column, from kyphosis (forward bend) to lordosis (backward bend).

The surface of the seat pan must support the weight of the upper body comfortably and securely. Hard surfaces generate pressure points that can be avoided by suitable upholstery, cushions, or other surface materials that elastically or plastically adjust to body contours.

The only inherent limitation to the size of the seat pan is that it should be short enough that the front edge does not press into the sensitive tissues near the knee. Usually, the seat pan is between 38 and 42 cm deep and at least 45 cm wide. A well-rounded front edge is mandatory. The side and rear borders of the seat pan may be slightly higher than its central part.

The height of the seat pan must be widely adjustable, preferably down to about 37 cm and up to 51 or even 58 cm, to accommodate persons with short and long lower legs. It is very important that all adjustments, especially in height and tilt angle, can be easily done while one sits on the chair.

Figure 13–23 illustrates major dimensions of the seat pan.

Backrests

Two opposing ideas have been promoted. One advocates not having a backrest at all, so that trunk muscles must remain

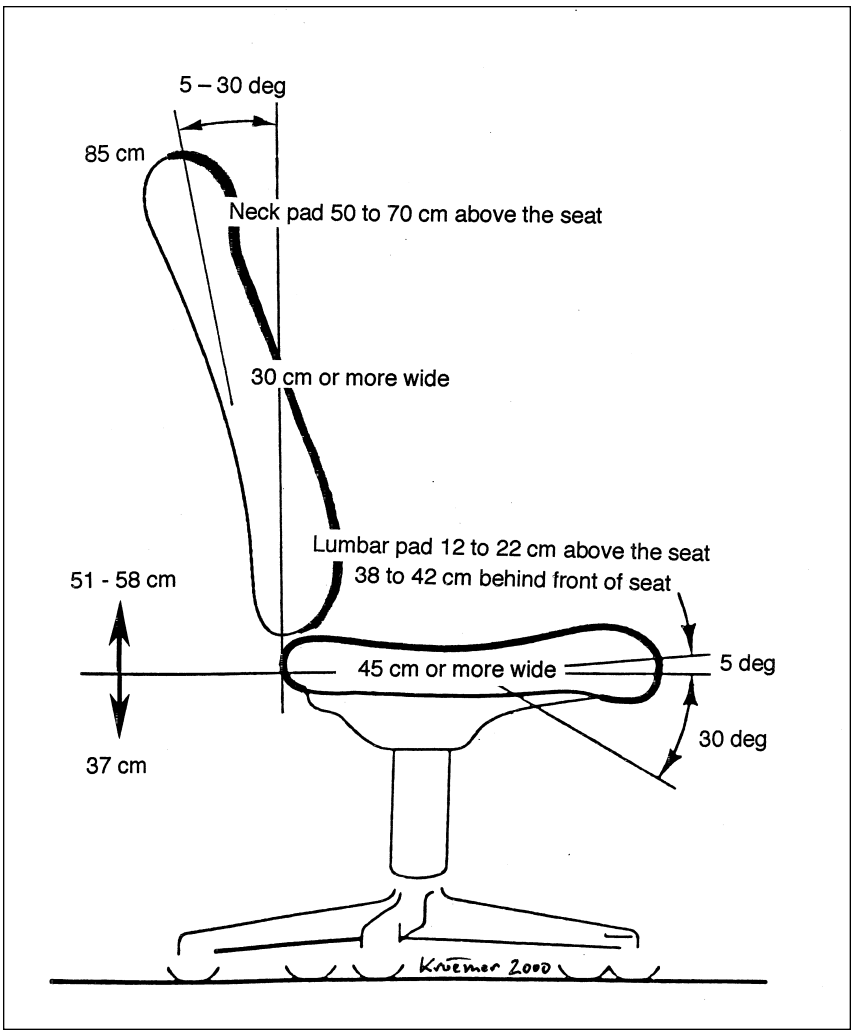

Figure 13–23. Essential dimensions of seat pan and backrest. Adapted from Kroemer et al (2001), *Ergonomics: How to Design for Ease and Efficiency*, 2nd ed. Upper Saddle River, NJ: Prentice-Hall.

continually active to keep the upper body in balance. However, this concept (called active sitting) has not become very popular, for obvious reasons.

Most people think that a backrest is desirable for several reasons. One is that the back support carries some of the weight of the upper body and hence reduces the load that otherwise the spinal column must transmit to the seat pan. A second reason is that a lumbar pad, protruding slightly in the lumbar area, helps to maintain lumbar lordosis, believed to be beneficial. A third, related reason is that leaning against a suitably formed backrest is relaxing.

Studies have shown the importance of supporting the back by leaning it on a rearward-declined backrest. Andersson et al summarized the available findings in 1987 and concluded, "In a well-designed chair the disc pressure is lower than when standing" (p.1113). Relaxed leaning against a declined backrest is the least stressful sitting posture. This is often freely chosen by persons working in the office if there is a suitable backrest available: "... an impression which many observers have already perceived when visiting offices or workshops with VDT workstations: Most of the operators do not maintain an upright trunk posture.... In fact, the great majority of the operators lean backwards even if the chairs are not suitable for such a posture" (Grandjean et al, 1984, pp 100–101).

Of course, the backrest should be shaped to support the back fittingly. Apparently independently from each other, Ridder (1959) in the United States and Grandjean and his co-workers (1963) in Switzerland found in experiments that their subjects preferred similar backrest shapes. In essence, these shapes follow the curvature of the rear side of the human body. At the bottom, the backrest is concave to provide room for the buttocks, above is slightly convex to fill in the lumbar lordosis. Above the lumbar pad, the backrest surface is nearly straight but tilted backward to support the thoracic area. At the top, the backrest is again convex to follow the neck lordosis.

Combined with a suitably formed and upholstered seat pan, this shape has been used successfully for seats in automobiles, aircraft, passenger trains, and for easy chairs. In the traditional office, the boss enjoyed these first-class shapes while the rest of the employees had to use simpler designs. The so-called secretarial chairs had a small, often hard-surfaced seat pan and a slightly curved back support for the

low back. The more recently designed task chair is an improved version.

The backrest should be as large as can be accommodated at the workplace: this means up to 85 cm high and at least 30 cm wide. To provide support from the head and neck on down to the lumbar region, it is usually shaped to follow the back contours, specifically in the lumbar and the neck regions. Many users appreciate an adjustable pad or an inflatable cushion for supporting the lumbar lordosis. The lumbar pad should be adjustable from 12 to 22 cm, the cervical pad from 50 to 70 cm above the seat surface.

The angle of the backrest must be easily adjustable while the person using it is seated. It should range from slightly behind upright (95 degrees from horizontal) to about 30 degrees behind vertical (120 degrees), with further declination for rest and relaxation desirable. Whether or not the seatback angle should be mechanically linked to the seat pan angle is apparently a matter of personal preference.

Figure 13–23 illustrates major dimensions of the backrest.

Armrests

Armrests can provide support for the weight of hands, arms, and even portions of the upper trunk. Thus, armrests can be of help, when they have a suitable load-bearing surface and are padded, even if only for short periods of use. Adjustability in height, width, and possibly direction is desirable. However, armrests can also hinder moving the arm, pulling the seat toward the workstation, or getting in and out of the seat. In these cases, having short armrests, or none, is appropriate.

Footrests

Hassocks, ottomans, and footstools have long been popular to put up one's feet, but footrests in the office usually indicate deficient workplace design, especially that a seat pan cannot be sufficiently lowered for the seated person. If a footrest is used, it should not be so high that the sitting person's thighs are nearly horizontal. A footrest should not consist of a single bar or other small surface because this restricts the ability to change the posture of the legs. Instead, the footrest should provide a support surface that is about as large as the total legroom available in the normal work position.

WORK SURFACE, KEYBOARD SUPPORT

The height of the workstation depends largely on the activities to be performed with the hands, and how well and exactly the work must be viewed. Thus, the main reference point for ergonomic workstations is the elbow height of the person, and the location of the eyes. Both depend on how one sits or stands, upright or slumped, and how one alternates among postures.

The table or other work surface should be adjustable in height between about 60 and 70 cm, even a bit higher for very tall persons, to permit proper hand/arm and eye locations. Often, a keyboard or other input device is placed on the work surface, or connected to it by a tray. A keyboard tray can be useful, especially if the table is a bit high for a person, but it also may reduce the clearance height for the knees. The tray should be large enough for keyboard and trackball or mousepad unless these are built into the keyboard.

SITTING AND BACK PAIN

The posture and movements of the spinal column have been of great concern to physiologists and orthopedists. This is due to the fact that so many persons suffer from annoyance, pain, and disorders in the spinal column, particularly in the low back and neck areas. Explanations have been sought in the human body's "not being built for long sitting or standing," or not being fit because of lack of exercise, or having undergone degeneration, particularly of the intervertebral discs. Physical activities and special exercises can improve fitness. Caution must be applied, however, when selecting exercises; some are appropriate, others are of questionable value, but several are outright dangerous or injurious, as Lee and co-authors pointed out in 1992.

The most easily applied remedy is to alternate often between walking, standing, and sitting. When long-time sitting is required, then the design of the seat and other furniture and equipment are critical; e.g., a tall and well-shaped backrest that reclines helps to support the back and head during work and allows one to take relaxing breaks. While sitting, one should change position often. This can be done purposefully by the person, perhaps with the help of automatic devices that make cushions on the seat or backrest pulsate on and off, or that effect small changes in the angles of seat pan and backrest

Designing the Stand-Up Workstation

Standing up while doing computer work seems like a return to the habits of office clerks common around 1900. Yet, moving about and standing on one's feet, at least for a period of time, can be a welcome change from sitting, provided that the person does it at his or her own choosing. One may opt to stand for reading or writing or telephoning. Stand-up workstations can use a second computer to which work activities can be switched from the sit-down workstation for a while, or one can use a lap-top computer there. Some people prefer standing and walking altogether to sitting in the office.

Stand-up workstations should be adjustable to have the working area used for writing or computer inputs at approximately elbow height when standing, between 0.9 and 1.2 meters above the floor. As in the sit-down workstation, the display should be located close to the other visual targets and directly behind the keyboard. If the work surface is used for reading or writing, it may slope down slightly toward the person. A footrest at about two-thirds knee height (approximately 0.3 m) allows the person to prop one foot up on it temporarily. This brings about welcome changes in pelvis rotation and spine curvature.

Nonresilient floors, such as made of concrete, can be hard on peoples' feet, legs, and backs. Carpets, elastic floor mats,

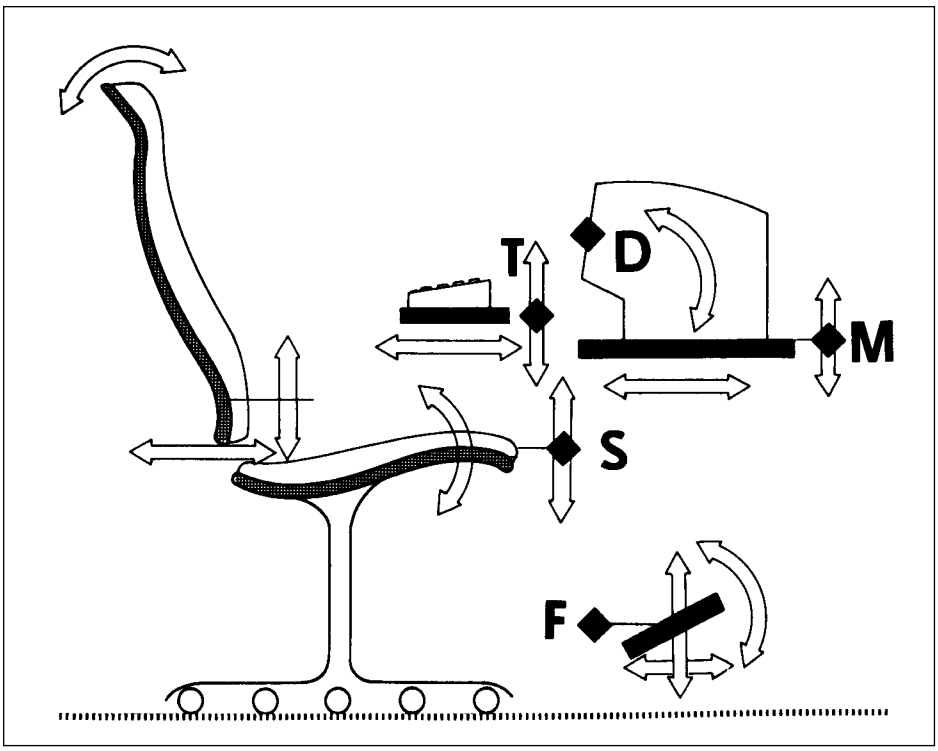

Figure 13–24. Adjustment features of a computer workstation. Key: S = seat height; T = table height; F = footrest height; D = monitor height; M = support height. (Reprinted with permission from Kroemer 2001.).

and soft shoe soles can reduce strain. Appropriate friction between soles and the walkway surface helps to avoid slips and falls.

Designing the Home Office

Everything said previously applies to the home office. If you work only for short periods of time in your office at home, then the old dining table and the odd kitchen chair probably will not harm you. But as soon as you get serious about using your home office, working in it for hours, you should become very conscious about the working conditions there. Equip your office with carefully selected furniture, where the chair and other components of the workstation fit each other well—and, most importantly, fit you well. Don't fall for furnishings that are un-ergonomic, such as shelving units that make you put up the monitor higher than the keyboard, or that do not provide sufficient space for the mouse pad. This is your own workspace, put together for your comfort and ease at work, and it does not have to be similar to anybody else's set-up—nor does it have to be expensive, because some simple furniture on the market can serve you well.

Get a quality computer with an up-to-date display and with input-suitable devices. Select a keyboard that feels convenient to you, but consider voice input that might serve you well. If you travel much with your hand-held or lap-top computer, consider a docking station. Do you want to use a lap-top computer in your office as well? Select a room with good lighting that is separate and quiet and well heated and cooled. You will probably spend more time in your home office than you expected, and your well-being is worth the effort and money that you spend.

Fitting It All Together

A bad or mediocre office is not instantly converted into a good one by changing to a different computer or by simply putting up a better chair. All the components, equipment, furniture, lighting, and climate, must fit each other (see Figure 13–24) and the person in the office must be willing and able to take advantage of all the offered possibilities. Equipment change must go with change in mental attitude. This applies not only to the working person, but also to the attitude of management: The expectation that all furniture and the postures of all the office workers must look alike is not reasonable; the micromanaging style of the 1980s is insufferable; the 1990s' "lean and mean" behavior of the almighty boss who calls all the shots is counterproductive.

Healthy, productive organizations use ergonomics on all levels. In 1999, Liberty Mutual Insurance Company completed an investigation of the impact of flexible office workspaces and ergonomic training on employee health and performance. Twenty office workers moved into new, adjustable workspaces while another twenty occupied new but corporate-specific workplaces. All 40 people received training in ergonomics. The expectation was that by giving employees more control over their environment and a better understanding of ergonomic principles, performance would improve and health problems diminish. The results of the 18-month study confirmed the expected: Combined with ergonomic training, the flexible workspace increased individual performance and group collaboration. This was accompanied by a nearly one-third reduction in back pain and a two-thirds reduction in upper limb pains among the employees who had more control over their environment.

CONTROLS AND DISPLAYS

Much research has been performed on controls and displays; in fact, in human factors engineering, the period after World War II is often called the "knobs and dials era." Summaries of the findings have been published in *Military Standards* (see especially 1472F of 1999) and by Cushman and Rosenberg (1991), Kroemer et al (2001), Salvendy (1997), and Woodson et al (1991). The following recommendations are brief excerpts from Chapter 10 of the Kroemers' book.

Light Signals

A *red* signal light shall be used to alert an operator that the system or any portion of the system is inoperative or that a successful mission is not possible until appropriate corrective or override action is taken. Examples of indicators that should be coded in red light are those that display such information as "no-go," "error," "failure," "malfunction."

A *flashing red* signal light shall be used only to denote emergency conditions that require immediate operator action or to avert impending personnel injury, equipment damage, or both.

A *steady red* signal alerts the operator that the system or a portion thereof is inoperative and that a successful operation is not possible until appropriate correcting or overriding action has been taken.

A *yellow* signal light shall be used to advise an operator that a marginal condition exists. Yellow shall also be used to alert the operator to situations for which caution, rechecking, or unexpected delay is necessary.

A *green* signal light shall be used to indicate that the monitored equipment is in satisfactory condition and that it is all right to proceed; i.e., green signifies "go ahead," "in tolerance," "ready," "function activated," "power on," and the like.

A *white* signal light shall be used to indicate system conditions that do not have right or wrong implications, such as alternative functions (e.g., "rear steering on") or transitory conditions (e.g., "fan on"), provided such indication does not imply the success or failure of the operation.

A *blue* signal light may be used as an advisory, but common use of blue should be avoided.

Labels

Controls, displays, and any other items of equipment that must be located, identified, manipulated, or read shall be appropriately and clearly labeled to permit rapid and accurate performance. No label will be required on equipment or controls whose use is obvious to the user.

Labeling characteristics are determined by such factors as

- the accuracy of identification required
- the time available for recognition or other responses
- the distance at which the labels must be read
- the illumination level and color characteristics of the illuminant
- the critical nature of the function labeled
- the consistency of label design within and between systems

Orientation. Labels and the information printed thereon should be oriented horizontally so that the labels may be read quickly and easily from left to right.

Location. Labels shall be placed on or very near the items they identify so as to eliminate confusion with other items and labels.

Standardization. Placement of labels shall be consistent throughout the equipment and system.

Equipment functions. Labels should primarily describe the functions of equipment items. Secondarily, the engineering characteristics or nomenclature may be described.

Abbreviations. Standard abbreviations shall be selected. If a new abbreviation is required, its meaning shall be obvious to the intended reader. Capital letters shall be used. Periods shall be omitted except when needed to preclude misinterpretation. The same abbreviation shall be used for all tenses and for both singular and plural forms of a word.

Brevity. Labels shall be as concise as possible without distorting the intended meaning or information and shall be unambiguous. Redundancy shall be minimized. If the general function is obvious, only the specific function shall be identified (e.g., "frequency" as opposed to "frequency factor").

Familiarity. Words shall be chosen on the basis of operator familiarity whenever possible, provided the words express exactly what is intended. Brevity shall not be stressed if the results will be unfamiliar to operating personnel. Common, meaningful symbols (e.g., %, and +) may be used as necessary.

Visibility and legibility. Labels and placards shall be designed to be read easily and accurately at the anticipated operational reading distances, within the anticipated vibration/motion environment, and at minimally expected illumination levels. The following factors must be taken into consideration: contrast between the lettering and its immediate background; the height, width, stroke width, spacing, and style of letters; and the specular reflection of the background, cover, or other components.

AVOIDING CUMULATIVE TRAUMA DISORDERS

One distinguishes single-event injuries, called acute or traumatic, from those disorders that stem from oft-repeated actions whose cumulative effects result in an injury. In the United States, OSHA is making the reduction of such injuries a major goal of its investigation and enforcement program, which is of great concern to industry and the legal profession.

Cumulative strain injuries are the result of a series of *microtraumata,* each of which can "insult" the body, but not

lead to discernible damage. In their accumulation over time, however, the microstresses can cause discernible health complaints, and result in clinically manifest disorders or injuries which reduce the ability to perform related work. Different terms have been used to describe these conditions, such as cumulative trauma disorder (or injury, or syndrome), overuse disorder, repetitive motion injury, repetitive strain injury, occupational motion-related injury, regional musculo-skeletal disorder, work-related disorder, osteoarthrosis, rheumatic disease, etc. In this text, the term "cumulative trauma disorder" (CTD) is used.

Putz-Anderson (1988) defined CTD as a "*disorder of the muscular and/or tendinous and/or osseous and/or nervous system(s); caused, precipitated, or aggravated by repeated exertions or movements of the body.*"

Not a New Problem

Nearly 300 years ago, Bernadino Ramazzini (Wright, 1993) described health problems (that today we would call CTDs) appearing in workers who do violent and irregular motions and assume unnatural postures. Yet, Ramazzini also reported CTDs to occur among office clerks, believing that these events were caused by repetitive movements of the hands, by constrained body postures, and by excessive mental stress. Such activity-related disorders have been known for a long time, for example, washer woman's sprain, game keeper's thumb, telegraphist's cramp, writer's cramp, trigger finger, and tennis or golfer's elbow.

CTDs in Industry

Early in the 20th century, many CTD cases were reported from various kinds of industrial and agricultural work. In 1961, Peres wrote on page 6 in his treatise on "Process Work Without Strain":

> *It has been fairly well established, by experimental research overseas and our own experience in local industry, that the continuous use of the same body movement and sets of muscles responsible for that movement during the normal working shift (not withstanding the presence of rest breaks), can lead to the onset initially of fatigue, and ultimately of immediate or cumulative muscular strain in the local body area.*

Peres listed the muscles most frequently affected in this order: those which control the movements of the fingers, of the hand, the forearm, and the upper arm. His special concerns were movements of the hand and fingers, and in particular injuries to tendons and tendon sheaths due to excessively repetitive motions of fingers. He said that fairly few cases were the result of a direct trauma while many were related to repetitive use.

Thus, around 1960, it was known (as Peres stated on page 10) that "cumulative muscle strain in industry is probably the reason for more injuries than has been generally thought." On page 11, Peres said:

> *It is sometimes difficult to see why experienced people, after working satisfactorily for, say, 15 years at a given job, suddenly develop pains and strains. In some cases these are due to degenerative arthritic changes and/or traumatic injury of the bones of the wrist or other joints involved. In other cases, the cause seems to be compression of a nerve in the particular vicinity, as for example, compression of the median nerve in carpal tunnel syndrome. However, it may well be that many more are due to cumulative muscle strain arising from wrong methods of working.*

CTDs of Keyboard Users

In 1964, Kroemer reported:

> *Steno-typists and other persons working with keyboards are often afflicted with disorders of tendons, tendon sheaths, and synovial tissues of tendons, and of the tendon and muscle attachments. At this moment it is unknown what causes or aggravates these disorders. Possible sources may be, for example, the force needed to operate the keys, the displacement of the keys, or the frequency of operation. Hettinger (1957) attributes particular importance to the frequency. Practical experiences give reason to assume that "electrical" typewriters are advantageous over "mechanical" ones. With electrical machines, the typing frequency is certainly not lower, but the key displacement and the operational force are smaller.—The body posture is indicted in several publications. Inappropriate posture and extensive muscle tension of the arms are mentioned, and the working position and direction of arms and hands are indicated. The disadvantageous posture of arms and hands appears to be an important but generally little considered attribute of the work with typewriters and other keyboard machines as indicated already in 1926 by Klockenberg and in 1931 by the Allgemeiner Freier Angestelltenbund.*

What Causes CTDs?

Cumulative trauma disorder (CTD) is used here as a collective term for syndromes with or without physical manifestations. It is commonly characterized by discomfort, persistent pain, impairment, or disability in joints, muscles, tendons, and other soft tissues. It is often caused, precipitated or aggravated by repetitive and/or forceful motions. It can occur in diverse occupational activities such as assembly, manufacturing, meat processing, agricultural work, packing, sewing, and keying.

While the occurrence of CTDs, their diagnoses, and medical treatments were fairly well-known and established

by the middle of the 20th century, their relationships to occupational activities have been hotly argued. There is the point of view that body "usage within reason" should not lead to repetitive injuries. Individuals may be predisposed, particularly persons suffering from arthritis, diabetes, endocrinological disorders; also, such events as pregnancy, use of oral contraceptives, and gynecological surgery seem to be related to statistical occurrence. The fear of contracting CTDs or other psychosocial circumstances may lead to a sudden lowering of thresholds for discomfort which are normally acceptable, in the so-called RSI (repetition strain injury) epidemic in Australia in 1983–1988. Some people who claim repetitive injuries are suspected to suffer from normal fatigue, to be malingerers, or to have compensation neurosis.

Yet, the prevalent position taken in the current literature is that repetitive activities, as well as vibrations acting on the body, are causative, precipitating, or aggravating, regardless of whether they occur at work or during leisure (Bernard, 1997; Kuorinka & Forcier, 1995; National Research Council, 1998, 1999; Nordin et al, 1997). The major activity-related factors in repetitive strain injuries are rapid, often repeated movements, forceful exertions, static muscle loading (often to maintain posture), vibrations, and cooling of the body. Their negative effects are, or may be, aggravated by inappropriate organizational and social factors (Carayon et al, 1999; Moon & Sauter, 1996). Yet, how and whether they do so is difficult to assess.

Psychosocial factors include social support and workplace stress, job content, variety, demand, control, satisfaction, and enjoyment. Social support appears to have a mediating effect on stress. Among the organizational variables, poor job content (e.g., in terms of task identity and integration) and high demand have been found to be related to higher rates of musculoskeletal disorders; to a smaller extent, this also seems to be true for job control. Psychological stress has some causal plausibility but it is weaker than for individual and biomechanical variables. Altogether, social and organizational variables, even when found statistically significant for the generation of musculoskeletal disorders, are not large factors (National Research Council, 1999).

Work Factors That Can Cause CTDs

Repetitiveness is a matter of definition ("more than once per time unit") and what is slow or high depends on the specific activities or body part involved. For industrial work, Silverstein (1985) proposed that high repetitiveness be defined as a cycle time of less than 30 seconds, or as more than 50 percent of the cycle time spent performing the same fundamental motion.

Forcefulness is also a matter of definition and what is low or high depends on the specific activities or body part involved. Silverstein (1985) suggested that high force exerted with the hand, e.g., more than 45 N, may be a causative factor for occupational disorders. Yet the force applied to a computer key is only about one newton, which, however, translates to a multiple thereof in tension force in the finger tendon (Rempel et al, 1997, 1999).

Static muscle tension, often generated to maintain body posture, when high enough is stressful. If muscles must remain contracted at more than about 15 percent of their maximal capability, circulation is impaired. This can result in tissue ischemia and delayed dissipation of metabolites. Body position can also affect passage space for blood, nerves, and tendons. For example, extended (dropped) or flexed (elevated) wrists reduce the available lumen (cross section) of the carpal tunnel, and hence generate a condition that may cause carpal tunnel syndrome, particularly in persons with small wrists (Morgan, 1991). In fact, any strong deviation of the wrist from the straight position, and pronation (inward twisting) or supination (outward twisting) of the forearm especially with a bent wrist, and the pinch grip, are stressful.

Cumulative Injuries to the Body

Biomechanically, one can model the human body as consisting of a bony skeleton whose segments connect in joints and are powered by muscles that bridge the joints. The muscle actions are controlled by the nervous and hormonal systems and maintained through a network of blood vessels.

Cumulative injuries occur often in connective soft tissues, particularly to tendons and their sheaths. They may irritate or damage nerves and impede blood flow. They are frequent in the hand-wrist-forearm area (one example is the carpal tunnel syndrome, discussed in more detail below), in shoulder and neck, and in the back (often associated with load handling, especially lifting—see earlier in this chapter). Repetitive strains may even damage bone, such as the vertebrae.

BONES

The skeletal system of the human body is composed of some 200 bones and articulations and connective tissue. *Bones* provide the stable internal framework for the body. One distinguishes between flat axial bones, such as in the skull, sternum and ribs, and pelvis; and long cylindrical bones such as in the arms and legs. The long bones act, in mechanical terms, as the lever arms at which muscles pull about the articulations that join the bones. While bone is firm and hard and thus can resist high strain, it still has certain elastic properties. In childhood, when mineralization is low, bones are highly flexible. In contrast, bones of old people are highly mineralized and changed in geometry and therefore more brittle, effects often connected with osteoporosis. Bones can be shattered or broken through sudden impact or torque, and they can be damaged through continual stresses, such as in vibration.

CONNECTIVE TISSUES

Bones are connected to each other and with other elements of the body through connective tissues. *Cartilage* is a translucent and elastic material found at the ends of the ribs, in

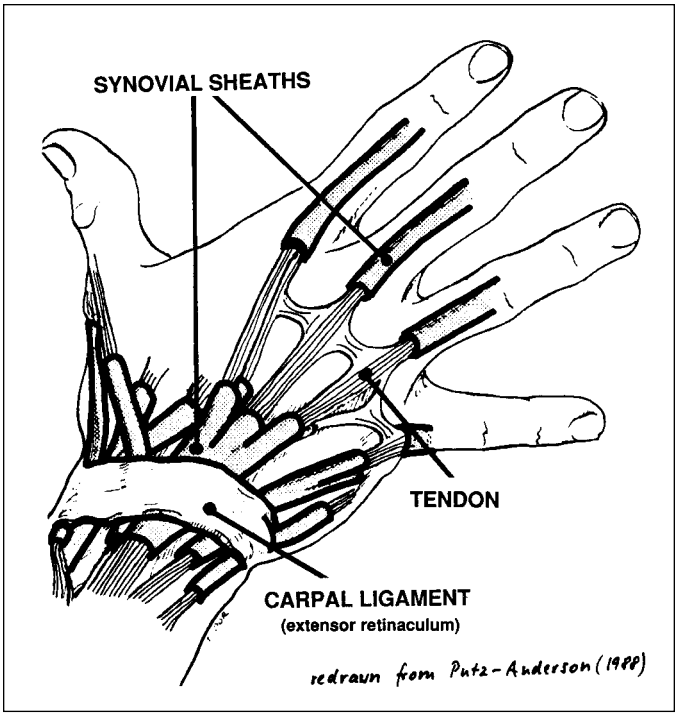

Figure 13–25. Tendons and their sheaths in the back of the hand. (Redrawn from Putz-Anderson 1988.)

joint surfaces of the articulations, and as discs between the vertebrae of the spinal column. Other connective tissues that are less elastic are called *ligaments* when they connect bones, and *tendons* when they connect muscle with bone. *Fascia* wraps organs or muscles. Fascial tissue condenses at the origin and insertion ends of muscle to tendons. Many but not all tendons are encapsulated by fibrous *sheaths* (see Figure 13–25). They allow a gliding motion of the tendon against surrounding materials which is facilitated by a viscous fluid, synovia, that reduces friction with the inner lining of the sheath. Particularly in the wrist and digits, sheaths keep tendons close to bones, acting as guides or pulleys for the pulling actions of the muscles.

NERVOUS CONTROL

The "peripheral" nervous system transmits information about events outside and inside the body from various sensors along its feedback pathways to its "central" part, the spinal cord and brain. Here, decisions about appropriate reactions and actions are made. Accordingly, action signals are generated and sent along the feed-forward pathways to the muscles. Thus, proper functioning of the sensors, such as in the hands, and of the nervous pathways to and from the brain is essential for the flow of information and of control signals in the nervous system.

BLOOD NETWORK

A network of arterial blood vessels provides oxygen and nutrients contained in working muscles and other organs. While passing through a muscle, metabolic waste products (such as lactic acid, carbon dioxide, heat, and water) are removed into the venous network. In addition, arterial blood transports hormones and other products of the internal glands which, parallel to the nervous system, regulate actions of body organs. Thus, blood flow is essential to working muscles for their proper functioning.

Which Body Components Are at Risk for CTDs?

While bones (except vertebrae) are not usually injured in the context of CTD, joints, muscles, and tendons and their related structures are at risk, as well as nerves and blood vessels.

SOFT TISSUES

A strain is an injury to muscle or tendon. Muscles can be stretched, which is associated with aching and swelling. A group of fibers torn apart is a more serious injury. If blood or nerve supply is interrupted for an extended time, the muscle atrophies.

Tendons contain collagen fibers, which neither stretch nor contract. Tendon surfaces can become rough, impeding their motion along other tissues. If overly strained, tendon fibers can be torn and scar tissue may form that creates chronic tension and is easily re-injured.

Gliding movement of a tendon in its sheath, caused by muscle contraction and relaxation, can be 5 cm in the hand when a finger is moved from fully extended to completely flexed. Synovial fluid in the tendon *sheath*, acting as a lubricant to allow easy gliding, may be diminished, which causes friction between tendon and its sheath. First signs of inflammation are feelings of tenderness and warmth, followed by discomfort and pain.

Inflammation of a tendon sheath is a protective response of the body. The feeling of warmth and swelling stems from the influx of blood. Compression of tissue either from swelling or mechanical pressure produces a sensation of pain. Movement of the tendon within its compressive surroundings is hindered. Forced movement, particularly when often repeated, may cause the inflammation of additional fiber tissue, which in turn can establish a permanent (chronic) condition of a swollen tendon and/or sheath that, in course, impedes tendon movement.

A *bursa* is a small, flat, synovia-filled sac lined with a slippery cushion which prevents rubbing of a muscle or tendon against bone. An often used muscle or tendon, particularly if it has become roughened, may irritate its adjacent bursa, setting up an inflammatory reaction, which inhibits free movement.

When a joint is displaced beyond its regular range, fibers of a *ligament* may be stretched, torn apart, or pulled from the bone. This is called a "sprain," often resulting from a single trauma but also possibly caused by repetitive actions. Injured ligaments may take weeks or even months to heal because their blood supply is poor. A ligament sprain can bring about a lasting joint instability and hence increases the risk of further injury.

NERVES

Nerves can also be affected by repeated or sustained pressure. Such pressure may stem from bones, ligaments, tendons, tendon sheaths, and muscles within the body, or from hard surfaces and sharp edges of work places, tools, and equipment. Pressure within the body can occur if the position of a body segment reduces the passage opening through which a nerve runs. Another source of compression, or an added one, may be swelling due to inflammation of other structures within this opening, such as tendons and tendon sheaths. The carpal tunnel syndrome (discussed below) is a typical case of nerve compression.

There are three different systems of nerve fibers which serve different functions: motor, sensory, and autonomic.

Impairment of a *motor nerve* reduces the ability to transmit signals to the innervated motor units in muscle. Thus, motor nerve impairment impedes the controlled activity of muscles, and hence reduces the ability to generate force or torque to tools, equipment, and other external objects.

Sensory nerve impairment reduces the information that can be transmitted from sensors to the central nervous system. Sensory feedback is very important for hand activities because it contains information about force applied, position assumed, and motion experienced. Sensory nerve impairment usually brings about sensations of numbness, tingling, or even pain. The ability to distinguish hot from cold may be reduced.

Impairment of an *autonomic nerve* reduces the ability to control such functions as temperature by sweat production in the skin. A common sign of autonomic nerve impairment is dryness and shininess of skin areas controlled by that nerve.

BLOOD VESSELS

Like nerves, *blood vessels* may be compressed. Compressing an artery results in reduced blood flow to the affected area; compression of a vein hinders the return of blood. Blood vessel compression thus means reduced supply of oxygen and nutrients to muscles, and impaired temperature control of tissues near tendons and ligaments. Such ischemia limits the possible duration of muscular actions and impairs muscle recovery from fatigue after activity. Vascular compression together with pressure on nerves is often found in neck, shoulder and upper arm. Names like thoracic outlet (or hyperabduction) syndrome, cervicobrachial disorder, brachial plexus neuritis, and costoclavicular syndrome describe the location of the condition.

Vibrations of body members, particularly of the hand, may trigger "vasospasms," which reduce the diameter of arteries, down to their complete closure. Of course, this impedes blood flow to the body areas supplied by the vessels, which become visible by blanching of the area, known particularly as white finger (or Raynaud's) phenomenon. Exposure to cold may aggravate the problem because it also can trigger vasospasms. Associated symptoms include intermittent or continued numbness and tingling in the fingers, with the skin turning pale and cold, and eventually loss of sensation and control in the fingers. The symptoms are often caused by vibrating tools such as pneumatic hammers, chainsaws, power grinders, power polishers. Frequent operation of keyboards may also constitute a source of vibration strain to the hand-wrist area.

Carpal Tunnel Syndrome

Among the best known cumulative trauma injuries is the carpal tunnel syndrome (CTS) first described 125 years ago (Armstrong, 1991). In 1959, Tanzer discussed 22 cases. Two of his patients had been working in large kitchens with much stirring and "ladled soup" twice daily for about 600 students. Two patients had recently started to milk cows on a dairy farm, two had done gardening with considerable hand weeding. One had been using a spray gun with a finger trigger, three worked in a shop in which objects were handled on a conveyor belt.

In 1966 and 1972, Phalen published reviews of 1,252 cases of CTS. These publications have become classics in the field; one of the most often applied tests for signs of CTS is called "Phalen's test." In 1975, Birkbeck and Beer described the results of their survey of work and hobby activities of 658 patients who suffered from CTS. Seventy-nine percent of these patients were employed in work requiring light, highly repetitive movements of the wrists and fingers. The authors indicated that this type of manual activity can be a causal factor in the development of CTS. They referred to a report published in 1947 by Brain, Wright, and Wilkinson, which described six cases of compression of the median nerve in the carpal tunnel. According to Birkbeck and Beer, even then it had been concluded that occupation is a causal factor. In 1976, Posch and Marcotte analyzed another 1,201 cases of CTS.

In 1964, Kroemer described the occurrence of syndromes in typists—see the quote presented earlier. In 1980, Maeda, Huenting, and Grandjean stated that impairments in hands and arms were found frequently with operators of accounting machines and that the disorders were related to working posture and operation of the keys. In 1981, Cannon, Bernacki, and Walter described a case-control study on the factors associated with the onset of carpal tunnel syndrome. They linked the occurrence of carpal tunnel syndrome to diverse etiological factors, which included injury and illness, use of drugs, and hormonal changes in women. *"Ergonomic theory relates the occurrence of the condition to repetitive movements of the wrists, performance of tasks with the wrists in ulnar deviation and chronic exposure to low-frequency vibrations*" (page 255). To support their statements and findings they listed 12 publications, all of them published in the 1970s.

In 1983, the American Industrial Hygiene Association acknowledged the prevalence and importance of CTS by publishing Armstrong's *An Ergonomics Guide to Carpal Tunnel Syndrome*. Carpal tunnel syndrome is one of the "occupational illnesses" in the hand/arm system among other repetitive trauma disorders such as tendinitis, synovitis, tenosynovitis, bursitis, trigger finger, and epicondylitis.

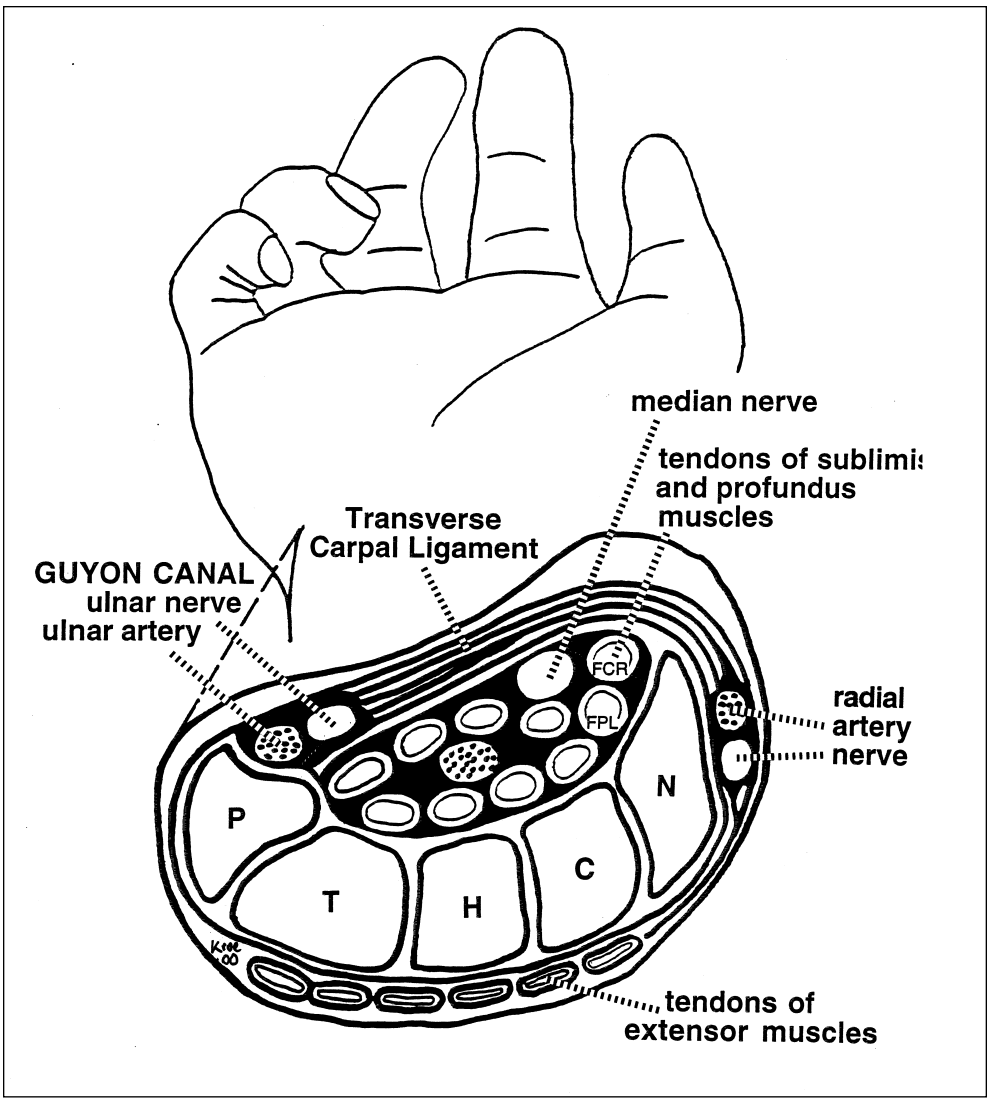

Figure 13–26. Cross-section of the carpal tunnel. The carpal bones (P, T, H, C, N) form the carpal "canal" which ligaments cover. Also shown are the tendons of the superficial (S) and profound (P) finger flexor muscles, flexors of the thumb (FCR, FPL), nerves, and arteries. (Adapted from Kroemer 1989.)

Thus, in the 1960s, 1970s, and early 1980s, CTS was well recognized as an often-occurring, disabling condition of the hand that can be caused, precipitated, or aggravated by certain work activities in the office and on the shop floor; of course, leisure activities may be involved as well.

On the palmar side of the wrist, near the base of the thumb, the carpal bones form a concave "floor" and the "walls" of the carpal canal. It has a "roof" that consists of three ligaments (the radial carpal, intercarpal, and carpometacarpal) covered by the transverse carpal ligament, which is firmly fused to the carpal bones. Thus, these bones and ligaments form a covered canal or tunnel, called the carpal tunnel. It is shown in Figure 13–26. In cross-section, it is roughly oval in shape. Through it pass the flexor tendons of the digits, as well as the median nerve. The radial nerve and artery, as well as the ulnar nerve and artery, are also confined in similar fashion. This crowded space is reduced if the wrist is bent up or down (flexed or extended), or pivoted to either side (ulnarly or radially). Any swelling of the tendons and of their sheaths reduces the space available for the tendons, the blood vessels, and the nerves.

The median nerve innervates the thumb, much of the palm, and the index and middle fingers, as well as most of the ring finger, but not its ulnar side. Pressure on the nerve reduces its ability to transmit signals: feed-forward to control proper functioning, feedback to report on existing conditions to the brain.

Occupational Activities and Related CTDs

Table 13–R lists conditions that are often associated with cumulative trauma (Kroemer 1992, Kroemer et al 2001). Of course, this list is neither complete nor exclusive. New occupational activities occur, and several activities may be part of the same job.

Repetitive and forceful exertions, particularly if combined, are generally thought to be responsible for a large portion of the CTD. Silverstein (1985) proposed that *high repetitiveness* may be defined as a cycle time of less than 30 seconds, or as more than 50% of the cycle time spent performing the same fundamental motion. Silverstein also suggested that *high force* by itself (for hand force, more than 45 newtons) may be a causative factor.

Table 13–R. *Common Cumulative Trauma Disorders*

Disorder Name	*Description*	*Typical Job Activities*
Carpal tunnel syndrome (writer's cramp, neuritis, median neuritis) (N)	The result of compression of the median nerve in the carpal tunnel of the wrist. This tunnel is an opening under the carpal ligament on the palmar side of the carpal bones. Through this tunnel pass the median nerve, the finger flexor tendons, and blood vessels. Swelling of the tendon sheaths reduces the size of the opening of the tunnel and pinches the median nerve and possibly blood vessels. The tunnel opening is also reduced if the wrist is flexed or extended or ulnarly or radially pivoted.	Buffing, grinding, polishing, sanding, assembly work, typing, keying, cashiering, playing musical instruments, surgery, packing, housekeeping, cooking, butchering, hand washing, scrubbing, hammering.
Cubital tunnel syndrome (N)	Compression of the ulnar nerve below the notch of the elbow. Tingling, numbness, or pain radiating into ring or little fingers.	Resting forearm near elbow on a hard surface or sharp edge or reaching over obstruction.
DeQuervain's syndrome (or disease) (T)	A special case of tendosynovitis that occurs in the abductor and extensor tendons of the thumb where they share a common sheath. This condition often results from combined forceful gripping and hand twisting, as in wringing cloths.	Buffing, grinding, polishing, sanding, pushing, pressing, sawing, cutting, surgery, butchering, use of pliers, 'turning' control such as on motorcycle, inserting screws in holes, forceful hand wringing.
Epicondylitis ("tennis elbow") (T)	Tendons attaching to the epicondyle (the lateral protrusion at the distal end of the humerus bone) become irritated. This condition is often the result of impacting or jerky throwing motions, repeated supination and pronation of the forearm, and forceful wrist extension movements. The condition is well-known among tennis players, pitchers, bowlers, and people hammering. A similar irritation of the tendon attachments on the inside of the elbow is called medial epicondylitis, also known as "golfer's elbow."	Turning screws, small parts assembly, hammering, meat cutting, playing musical instruments, playing tennis, pitching, bowling.
Ganglion (T)	A tendon sheath swelling that is filled with synovial fluid, or a cystic tumor at the tendon sheath or a joint membrane. The affected area swells up and causes a bump under the skin, often on the dorsal or radial side of the wrist. (Because it was in the past occasionally smashed by striking with a bible or heavy book, it was also called a "bible bump.")	Buffing, grinding, polishing, sanding, pushing, pressing, sawing, cutting, surgery, butchering, use of pliers, 'turning' control such as on motorcycle, inserting screws in holes, forceful hand wringing.
Neck tension syndrome (M)	An irritation of the levator scapulae and trapezius group of muscles of the neck, commonly occurring after repeated or sustained overhead work.	Belt conveyor assembly, typing, keying, small parts assembly, packing, load carrying in hand or on shoulder.

(Continues)

Table 13–R. *(Continued)*

Disorder Name	*Description*	*Typical Job Activities*
Pronator (teres) syndrome (N)	Result of compression of the median nerve in the distal third of the forearm, often where it passes through the two heads of the pronator teres muscle in the forearm; common with strenuous flexion of elbow and wrist.	Soldering, buffing, grinding, polishing, sanding.
Shoulder tendinitis (rotator cuff syndrome or tendinitis, supraspinatus tendinitis, subacromial bursitis, subdeltoid bursitis, partial tear of the rotator cuff) (T)	This is a shoulder disorder located at the rotator cuff. The cuff consists of four tendons that fuse over the shoulder joint, where they pronate and supinate the arm and help to abduct it. The rotator cuff tendons must pass through a small bony passage between the humerus and the acromion, with a bursa as cushion. Irritation and swelling of the tendon or of the bursa are often caused by continuous muscle and tendon effort to keep the arm elevated.	Punch press operations, overhead assembly, overhead welding, overhead painting, overhead auto repair, belt conveyor assembly work, packing, storing, construction work, postal letter carrying, reaching, lifting, carrying load on shoulder.
Tendinitis (tendinitis) (T)	An inflammation of a tendon. Often associated with repeated tension, motion, bending, being in contact with a hard surface, vibration. The tendon becomes thickened, bumpy, and irregular in its surface. Tendon fibers may be frayed or torn apart. In tendons without sheaths, such as within elbow and shoulder, the injured area may calcify.	Punch press operation, assembly work, wiring, packaging, core making, use of pliers.
Tendosynovitis (tenosynovitis, tendovaginitis) (T)	This disorder occurs to tendons inside synovial sheaths. The sheath swells. Consequently, movement of the tendon with the sheath is impeded and painful. The tendon surfaces can become irritated, rough, and bumpy. If then inflamed sheath presses progressively onto the tendon, the condition is called stenosing tendosynovitis. DeQuervain's syndrome is a special case occurring in the thumb, while the trigger finger condition occurs in flexors of the fingers.	Buffing, grinding, polishing, sanding, punch press operation, sawing, cutting, surgery, butchering, use of pliers, 'turning' control such as on motorcycle, inserting screws in holes, forceful hand wringing.
Thoracic outlet syndrome (neurovascular compression syndrome, cervicobrachial disorder, brachial plexus neuritis, costoclavicular syndrome, hyperabduction syndrome) (V, N)	A disorder resulting from compression of nerves and blood vessels between clavicle and first and second ribs at the brachial plexus. If this neurovascular bundle is compressed by the pectoralis minor muscle, blood flow to and from the arm is reduced. This ischemic condition makes the arm numb and limits muscular activities.	Buffing, grinding, polishing, sanding, overhead assembly, overhead welding, overhead painting, overhead auto repair, typing, keying, cashiering, wiring, playing musical instruments, surgery, truck driving, stacking, material handling, postal letter carrying, carrying heavy loads with extended arms.

(Continues)

Table 13–R. *(Concluded)*

Disorder Name	*Description*	*Typical Job Activities*
Trigger finger (or thumb) (T)	A special case of tendosynovitis where the tendon becomes nearly locked so that its forced movement is not smooth but snaps or jerks. This is a special case of stenosing tendosynovitis crepitans, a condition usually found with digit flexors at the A1 ligament.	Operating finger trigger, using hand tools that have sharp edges pressing into the tissue or whose handles are too far apart for the user's hand so that the end segments of the fingers are flexed while the middle segments are straight.
Ulnar artery aneurysm (V, N)	Weakening of a section of the wall of the ulnar artery as it passes through the Guyon tunnel in the wrist; often from pounding or pushing with heel of the hand. The resulting "bubble" presses on the ulnar nerve in the Guyon tunnel.	Assembly work.
Ulnar nerve entrapment (Guyon tunnel syndrome) (N)	Results from the entrapment of the ulnar nerve as it passes through the Guyon tunnel in the wrist. It can occur from prolonged flexion and extension of the wrist and repeated pressure on the hypothenar eminence of the palm.	Playing musical instruments, carpentering, brick laying, use of pliers, soldering, hammering.
White finger ("dead finger," Raynaud's syndrome, vibration syndrome) (V)	Stems from insufficient blood supply bringing about noticeable blanching. Finger turns cold, numb, tingles, and sensation and control of finger movement may be lost. The condition is due to closure of the digit's arteries caused by vasospasms triggered by vibrations. A common cause is continued forceful gripping of vibrating tools, particularly in a cold environment.	Chain sawing, jack hammering, use of vibrating tool, sanding, paint scraping, using vibrating tool too small for the hand, often in a cold environment.

N = nerve disorder; T = tendon disorder; M = muscle disorder; V = vessel disorder. (Adapted from Kroemer, 1992. Reprinted with permission of the American Industrial Hygiene Association.)

If muscles must remain contracted at more than about 15 to 20 percent of their maximal capability, circulation is impaired. This can result in tissue ischemia and delayed dissipation of metabolites, which constitute conditions of general physiological strain. *Posture* may be highly important. For example, dorsiflexion of the wrist ("dropped wrist") generates a condition likely to cause CTS. Maintained isometric contraction of muscles needed to keep a body part in an extreme position is often associated with a CTD condition. Inward or outward rotation of the forearm, especially with a bent wrist, any severe deviation of the wrist from its neutral position, and the pinch grip can be stressful.

Ergonomic Countermeasures

Exercise as a prophylactic measure is of questionable value. Proponents hope to "strengthen" tissues, but inappropriate exercising may worsen conditions. Lee, Swanson, Sauter et al (1992) evaluated a large number of proposed exercises and selected those that have been shown to be useful.

Ergonomic intervention depends on the stage. Early symptoms of CTD are reversible through work modification, rest breaks and possibly exercises. In the later stages, the patient must abstain from performing the causing work, and rest. This may go along with major changes in life-style and working capacity. Further medical treatments are physiotherapy, drug administration, and in some cases surgery, such as carpal tunnel release.

Of course, one should purposefully avoid the conditions that may lead to CTD. This is best done in the planning stage of a new job. For existing jobs, it is important to identify problems and symptoms early, to prevent injury through ergonomic work re-organization and work redesign.

At work, various ergonomic interventions can be taken. They start with suitable design of the work object and of the equipment and tools used. They include instruction on and training in proper habits. Among the managerial interventions are work diversification (the opposite of job simplification and specialization leading to repetition), relief workers, and rest pauses.

Suspicious jobs should be analyzed for their movement and force requirements using variants of the well-established industrial engineering procedure of motion and time study. Each element of the work should be screened for factors that can contribute to CTDs. After the job analysis has been completed, workstations, equipment, and work procedures

Table 13–S. *Ergonomic Measures to Avoid Cumulative Trauma Disorders*

CTD	*Avoid in General*	*Avoid in Particular*	*Do*	*Design*
Carpal tunnel syndrome	Rapid, often-repeated finger movements, wrist deviation	Dorsal and palmar flexion, pinch grip, vibrations between 10 and 60 Hz		
Cubital tunnel syndrome	Resting forearm on sharp edge or hard surface			
DeQuervain's syndrome	Combined forceful gripping and hard twisting			
Epicondylitis	"Bad tennis backhand"	Dorsiflexion, pronation		
Pronator syndrome	Forearm pronation	Rapid and forceful pronation, strong elbow and wrist flexion	Use large muscles, but infrequently and for short durations	The work object properly
Shoulder tendinitis, rotator cuff syndrome	Arm elevation	Arm abduction, elbow elevation	Let wrists be in line with the forearm	The job task properly
Tendinitis	Often-repeated movements, particularly with force exertion; hard surface in contact with skin; vibrations	Frequent motions of digits, wrists, forearm, shoulder	Let shoulder and upper arm be relaxed	Hand tools properly (" bend tool, not the wrist")
Tendosynovitis, DeQuervain's syndrome, ganglion	Finger flexion, wrist deviation	Ulnar deviation, dorsal and palmar flexion, radial deviation with firm grip	Let forearms be horizontal or more declined	Round corners, pad
Thoracic outlet syndrome	Arm elevation, carrying	Shoulder flexion, arm hyperextension		Place work object properly
Trigger finger or thumb	Digit flexion	Flexion of distal phalanx alone		
Ulnar artery aneurysm	Pounding and pushing with the heel of the hand			
Ulnar nerve entrapment	Wrist flexion and extension	Wrist flexion and extension, pressure on hypothenar eminence		
White finger, vibration syndrome	Vibrations, tight grip, cold	Vibrations between 40 and 125 Hz		
Neck tension syndrome	Static head posture	Prolonged static head/neck posture	Alternate head/neck postures	

(Adapted from Kroemer, 1992. Reprinted with permission of the American Industrial Hygiene Association.)

can be ergonomically re-engineered and re-organized to reduce the stress on the operator's body. Table 13–S, adapted from Kroemer (1989, 1992), provides an overview of generic ergonomic countermeasures.

Safe Thresholds and Doses?

The American National Standards Institute (ANSI) has established the Z365 committee to determine what is known about cumulative trauma disorders, and what standard procedures could be established to avoid these. The deliberations of the ANSI Z365 committees in the early 1990s indicated that much research must be conducted to single out and describe the components of activities that may lead to CTDs, and to understand how physical events overload body structures and tissues, and how, if at all, psychosocial conditions contribute. When these relationships are understood, it should be possible to establish threshold values or exposure doses for activity (job) factors such as force, displacement, repetition, duration, and posture, which separate suitable from unacceptable conditions. Such thresholds or doses could replace generic guidelines by specific ergonomic recommendations.

SUMMARY

The industrial hygienist is largely responsible for the health and well-being of people employed in industry, commerce,

service, and administration. Of course, this concern must be seen in the light of the goal to be productive, both in quantity and in quality. Fortunately, ergonomic/human factors recommendations usually bring about, directly or indirectly, improved job performance together with increased safety, health, and wellness. In recent years, both management and employee representatives, including unions, have cooperated in using ergonomics to increase the ease and efficiency at work.

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Chapter 14

Biological Hazards

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This chapter provides basic information on those hazards that are considered biological in nature. While the chapter focuses on work-related exposures to infectious microbiological agents, exposures to other biohazardous materials not associated with infectious agents are reviewed. Background on the development of the field of biological safety and considerations on the role of industrial hygienists and environmental health and safety professionals in the field are discussed. The principles of hazard identification, assessment, classification, and control and the diverse environments associated with biological exposures are examined. Material on current topics in biological safety including bloodborne pathogens, tuberculosis, bioterrorism, legionellosis, building-related bioaerosol problems, organic dust toxic syndrome, mycotoxins, endotoxins, and Pfiesteria is covered. Information on assessing compliance, current regulations and guidelines including large-scale containment guidelines, standard-setting groups, and relevant professional associations is reviewed. This chapter cannot begin to adequately cover biological hazards, so the reader is encouraged to use the provided references and resources to further gain insight into the field of biological safety.

Exposure to biological hazards in the workplace results in a significant amount of occupationally associated disease. Work-related illnesses due to biological agents such as infectious microorganisms, biological allergens, and toxins have been widely reported. However, in many workplaces their presence and resultant illnesses are not recognized. It has been estimated that the population at risk from occupational biohazards may be several hundred million workers worldwide (Dutkiewicz et al, 1988).

Dutkiewicz et al (1988), in a review of occupational biohazards, noted that some 193 biological agents are known to produce infectious, allergenic, toxic, and carcinogenic reactions in workers. Most of the identified biohazardous agents belong to the following groups:

- ➢ *Microorganisms and their toxins (viruses, bacteria, fungi, and their products): infection, inflammatory disease, or allergic reaction*
- ➢ *Arthropods (crustaceans, arachnids, and insects): bites or stings resulting in skin inflammation, systemic intoxication, transmission of infectious agents, or allergic reaction*
- ➢ *Allergens and toxins from higher plants: dermatitis from skin contact or allergic rhinitis or asthma as a result of inhalation*
- ➢ *Protein allergens from vertebrate animals (urine, feces, hair, saliva, and dander): hypersensitivity and inflammatory disease*
- ➢ *Other groups that pose a potential biohazard include lower plants other than fungi (lichens, liverworts, and ferns) and invertebrate animals other than arthropods (parasites such as protozoa, flatworms such as* Schistosoma*, and roundworms such as* Ascaris*)*

Workers engaging in agricultural, medical, and laboratory activities have been identified as being most at risk to occupational biohazards, but many varied workplaces have the potential for such exposure. A number of potentially hazardous workplaces are described in this chapter. Although biological hazards encompass a wide variety of biological agents, in large part this chapter concentrates on exposures to microorganisms and the substances associated with them. Although the chapter deals extensively with laboratory and medical environments, the concepts, principles, and exposure controls discussed here can be extrapolated to suit most occupations.

BIOLOGICAL SAFETY

The discipline of biological safety (biosafety) grew out of research involving biological warfare agents at Fort Detrick in Frederick, Md. The Chemical Warfare Service (for chemical and biological warfare) was established by the U.S. Army in 1941, and in 1942 the National Academy of Sciences (NAS) formed a biological warfare committee. Microbiologists from the American Society for Microbiology (ASM) served as advisors for biological warfare activities instituted by the Chemical Warfare Service.

From 1955 to 1968, the ASM maintained an advisory committee for the Fort Detrick Biological Defense Research Program (BDRP) to provide scientific advice on research programs, peer review for publications, and assistance with staff recruitment. Members of the safety staff at Fort Detrick were well-trained microbiologists capable of advising on safety matters related to work with virulent microorganisms. Because of the considerable concern for worker safety, as well as the need to protect the surrounding community, great care was taken to prevent accidental exposure and release of infectious agents. The containment principles developed at Fort Detrick by Dr. Arnold G. Wedum and his colleagues form the framework for the discipline of biosafety today. It is noteworthy to observe that this profession, which was formed as the result of concerns about biological warfare, is once again forced to address that same threat.

Following the discovery of recombinant DNA technology in the 1970s, the new era of biotechnology began. The ability to insert into host cells specific pieces of foreign DNA that replicate to produce a desired product has revolutionized the field of biology. Recombinant DNA technology, hybridoma technology, and protein and enzyme engineering are all components of the new biotechnology. The impact of biotechnology on research in health care, diagnostics, and agriculture, as well as many other industries such as food, chemical, mining, and petroleum, has been significant. Whether real, potential, or imaginary, genetic manipulation of microorganisms and cells brought with it a renewed concern for biological hazards. Employers and regulatory agencies took note of these concerns and began implementing or strengthening workplace biosafety programs. Today, with numerous human gene therapy experiments underway, scientists are moving closer to achieving the promise of this technology. The responsibility of the biosafety professional, infection control practitioner, or hospital epidemiologist again shifts to include the task of assessing the need for appropriate containment at the patient's bedside, in the pharmacy where the preparations are made, and among the attending staff and family members.

The appearance of a virus capable of destroying the human immune system (human immunodeficiency virus, or HIV) in the 1980s, coupled with the high incidence of occupationally acquired hepatitis B virus infection among healthcare workers, prompted the Occupational Safety and Health Administration (OSHA) to establish a standard that mandates protection of workers from occupational exposure to bloodborne pathogens (OSHA, 1991). This standard has heightened awareness and improved biosafety controls in the workplace considerably.

The biosafety professional uses similar practices to define and control hazards in the workplace as those used by industrial hygienists. Both are responsible for helping to anticipate, recognize, evaluate, and control hazards in the workplace. The biosafety professional has a microbiology background and the primary focus of their work is biological hazards (microorganisms), while the industrial hygienist is trained to deal with multiple hazards in the workplace—biohazards usually represent only a small portion of their work load. Biosafety professionals include microbiologists, biologists, molecular biologists, environmental health scientists, industrial hygienists, clinical health care professionals, veterinarians, chemists, and engineers. Regardless of their background and education, they must develop knowledge of the principles of epidemiology, disease transmission patterns, risk-assessment management, disinfection and sterilization, disease prevention, aerobiology, and environmental control.

HAZARD IDENTIFICATION

Microorganisms are a diverse group of microscopic organisms that includes bacteria, fungi, algae, protozoa, viruses,

and prions. Although pathogenic or disease-producing microorganisms represent only a small portion of the total microbial population, attention is often focused on them because of their negative impact on humans, plants, and animals. In addition to their ability to produce infectious diseases, microorganisms such as fungi produce spores capable of causing allergic and inflammatory reactions among workers. Toxins such as endotoxin, a component in the cell walls of gram-negative bacteria, and mycotoxins, natural products produced by fungi, have also been identified as occupational biohazards. Other biological agents such as pollen, mites, urine proteins, animal dander, and snake venoms, to list only a few, also fit within the broad scope of biological hazards.

Microorganisms

Microorganisms are divided into two categories: prokaryotes (organisms in which DNA is not physically separated from the cytoplasm) and eukaryotes (organisms containing a membrane-bound nucleus). Prokaryotes and eukaryotes are organisms because they contain all of the enzymes required for their own replication, as well as the biological equipment necessary to produce metabolic energy. This distinguishes them from viruses, which depend on host cells for replication.

Prokaryotes, characterized by their relatively small size (around 1 μm in diameter) and the absence of a nuclear membrane, are divided into two major groups: eubacteria and archaebacter (Brooks et al, 1998). The more commonly known bacteria fall into the eubacteria category and they are further divided into three groups: gram-negative eubacteria with cell walls, gram-positive eubacteria with cell walls, and cell wall-less eubacteria (*Mycoplasma*). The fourth group, archaebacteria, differ from eubacteria in that they live in extreme environments (high temperatures, high salt, or low pH) and carry out unusual metabolic reactions. The majority of microorganisms of medical interest are gram-negative or -positive cell walled organisms that are either aerobic, microaerophilic, or anaerobic rods, cocci, or spirals. These characteristics are used as the framework for an identification scheme in *Bergey's Manual of Determinative Bacteriology* (Holt et al, 1994).

In contrast to prokaryotes, eukaryotes are larger and contain a membrane-bound nucleus and organelles such as mitochondria. The microbial eukaryotes, or protists, fall into four major groups: algae, protozoa, fungi, and slime molds, with protozoa such as species of *Giardia*, *Trypanosoma*, *Toxoplasma*, and *Plasmodium* and species of fungi such as *Histoplasma*, *Aspergillus*, *Cryptococcus*, and *Coccidioides* being infectious agents of medical importance.

Viruses, whose unique properties distinguish them from other microorganisms, are totally dependent on their hosts for replication. They are inert outside of a host cell, and host-virus interactions are highly specific. Viruses, the smallest infectious agents, are 20–300 nm in diameter. Viral particles consist of nucleic acid molecules, either DNA or RNA, enclosed in a protein coat, or *capsid*. The capsid protects the nucleic acid and facilitates attachment to and penetration into the host cell by the virus. Once inside a cell, viral nucleic acid uses the host's enzymatic machinery for functions associated with viral replication. The host range of a given virus may be broad or extremely narrow, and viruses can infect unicellular organisms such as mycoplasmas, bacteria, algae, and all higher plants and animals. Classification of viruses is based on a number of properties such as nucleic acid type, size and morphology, susceptibility to physical and chemical agents, and presence of enzymes.

Viroids—small, single-stranded, covalently closed circular RNA molecules—cause diseases in plants. Because of their characteristics it is thought that they have evolved from transposable elements or retroviruses by deletion of internal sequences. To date, viroids have not been detected in animals or humans.

Prions—agents smaller by an order of magnitude than viruses—have been reported that have properties similar to viruses and cause degenerative disease in humans and animals. Scrapie, a disease of the nervous system of sheep, is caused by such an agent. Because of the novel properties of this agent, the term, prion, has been designated to denote these small proteinaceous infectious particles, which are resistant to inactivation by most procedures that modify nucleic acids (Prusiner, 1982). The tropical disease kuru and Creutzfeldt-Jakob (a form of human dementia) are caused by similar agents.

Although the amount of information provided here is necessarily limited, a wealth of accessible material is readily available. Readers are encouraged to consult microbiology references such as *Medical Microbiology* (Brooks et al, 1998), *ASM Manual of Environmental Microbiology* (ASM, 1997), *Microbial Ecology* (Atlas & Bartha, 1998), *Manual of Clinical Microbiology* (Murray et al, 1999), *Bioaerosols Handbook* (Cox & Wathes, 1995), and *Bioaerosols* (Burge, 1995).

Infection

Infection is a general term applied to the entry and development or multiplication of an infectious agent such as bacteria, protozoa, and the larval forms of multicellular organisms such as the helminths (intestinal parasites including roundworms and tapeworms) in the body of people, animals, or plants. It is further defined as an invasion of the body by pathogenic microorganisms and the reaction of the tissues to their presence and to the toxins generated by them (Chin, 2000, p 572).

Although human beings have microorganisms on every surface and in every external orifice of their bodies, only a small proportion of those agents are capable of producing an infection that could lead to disease in that person or, if communicable, in others. If the disease-causing agent arises from the microbial flora normally present in or on the body of a person (indigenous flora), its resulting infection is called endogenous. For example, most urinary tract infections are caused by agents such as *Escherichia coli* or *Pseudomonas* spp,

which are normally found in the feces of the patient. This example demonstrates the disease-causing potential of normal flora when they are able to reach a different site in the body. Normal flora can also take advantage of a lowering of host immunity to produce an infectious disease. Such infections occur in those who are immunocompromised by underlying disease processes or certain medications such as steroids and chemotherapy. Further information on normal flora can be found in Isenberg and D'Amato, 1991.

Individuals harboring communicable infectious agents without exhibiting signs of disease are called carriers. They can be a source of infection in coworkers, especially if the agent is transmitted by the aerosol route, as with measles or tuberculosis. Certain of these "wild-type" agents—strains found in nature, and therefore in the community—can sometimes also contaminate a sterile product in a laboratory environment. A vaccine strain being grown in cell culture can be contaminated by a worker who carries a different, potentially more virulent strain obtained in the community. The restriction of visitors and the use of approved vaccines are thus recommended when appropriate to protect the work being done.

Infections from microorganisms not normally found in or on the human body, but which gain entrance from the environment, are called exogenous infections. These agents gain entry into the host by inhalation, indirect or direct contact, penetration, or ingestion. Some agents routinely cause disease in healthy adult humans, whereas others, known as opportunists, require special circumstances of lowered host defense or overwhelming dose of exposure. Thus, infectious disease is not always the end result of the exposure to and colonization by an infectious agent. The end result depends on the virulence of the agent, the route of infection, and the relative immunity and health of the host.

Workers are expected to be healthy human adults, but should be medically assessed during a preplacement examination to determine fitness for specific work. Because exposures can occur to those involved with the work and, potentially, to those who merely enter the work area, all such individuals should be identified and assessed in order to prevent exposure and subsequent infection. The spread of infectious agents used in research or production to the outside environment, including the neighboring community, is rare.

Epidemiology of Work-Associated Infections

An unfortunate consequence of working with infectious microorganisms or materials contaminated with them is the potential for acquiring a work-associated infection. The literature includes numerous descriptions of occupational exposures indicating that persons who handle infectious materials are clearly at higher risk for infection than the general population.

It is generally accepted that work-associated infections are underreported in the scientific literature. This may be the result of employees' unwillingness to report such incidents for fear of loss of employment, issues of liability, or an employer's refusal to publish such material. Literature on work-associated infections, reported as case studies, usually focuses on diagnosis and treatment of the patient and frequently fails to assess the circumstances related to the occupational exposure.

In the absence of a comprehensive database on work-associated infections, epidemiological methods provide the tools to evaluate the extent and nature of worker exposure. Defining the event or illness/infection, determining the population at risk, establishing the factors affecting exposure, and developing intervention controls are all part of the process to prevent occurrence or recurrence of infections. Several times during the past 79 years these tools have been applied to the study of laboratory-associated infections. A review of this information is instructive.

A comprehensive survey of laboratory-associated infections gathered by Sulkin and Pike (Sulkin & Pike, 1951; Pike, 1978; Pike, 1979) focuses specifically on laboratory-acquired infections. Data compiled between 1930–1978 revealed 4,079 cases of clinically apparent infection classified by agent, source of infection (when known), and type of work involved. Of the total, 168 cases resulted in the worker's death. These numbers are considered low because the reporting of work-related infections is not required, and data on seroconversion (the production of antibodies in response to an infectious agent) or asymptomatic response to occupationally acquired microorganisms are rarely reported. The 10 most frequently reported agents or diseases associated with laboratory-acquired infections described by Pike were brucellosis, Q fever, hepatitis, typhoid fever, tularemia, tuberculosis, dermatomycosis, Venezuelan equine encephalitis, psittacosis, and coccidiodomycosis.

The Sulkin and Pike surveys revealed the most common routes of exposure to be percutaneous inoculation (needles/syringes, cuts or abrasions from contaminated items, and animal bites), inhalation of aerosols generated by accidents or by work practices and procedures, contact between mucous membranes and contaminated material (hands and surfaces), and ingestion (Pike, 1979). Eighteen percent of the infections were attributable to known accidents caused by either carelessness or other human error. Twenty-five percent of these acknowledged accidents involved needles or syringes. Most of the remaining accidents involved spills and sprays, injury with broken glass or other sharp objects, accidental aspiration using a pipet, and animal bites, scratches, or contact with ectoparasites. Unfortunately, the sources of exposure for the remaining 82 percent of infections were not easily identifiable. Although some could be attributed to handling infectious animals, clinical specimens, and discarded glassware and to aerosols, all that was known about most exposures was that the person had worked with or was in the vicinity of work with the agent.

From these laboratory data, it is apparent that people engaged in research activities acquired the greatest number of infections. Trained investigators, technical assistants, animal

caretakers, and graduate students experienced over three-quarters of the research-associated illnesses. The remainder occurred among clerical staff, dishwashers, janitors, and maintenance personnel. With rare exceptions, laboratory-acquired infections were not spread to the outside community.

In an attempt to extend the Sulkin and Pike data, Harding and Byers reviewed 206 U.S. and worldwide publications between 1979–1999 to determine the microorganisms associated with laboratory infections, the types of facilities in which the infection occurred, and the type of work activity associated with the event (Harding & Byers, 2000). During this 20-year period 1,267 symptomatic laboratory-associated infections were reported with 22 deaths. Aborted fetuses accounted for five of the deaths with four of these associated with *Brucella melitensis* (Al-Aska & Chagla, 1989; Georghiou & Young, 1991; Young, 1983; Young, 1991) and one with Parvovirus B19 (Cohen et al, 1988). The 10 most frequently reported infections were associated with *Mycobacterium tuberculosis*, *Coxiella burnetii*, hantavirus, arboviruses, hepatitis B virus, *Brucella* spp, *Salmonella* spp, *Shigella* spp, non-A, non-B hepatitis virus, and *Cryptosporidium* spp. Clinical (diagnostic) and research laboratories accounted for 96 percent (45% and 51% respectively) of the symptomatic infections in this recent survey, whereas 76 percent of the infections occurred in clinical and research laboratories (17% and 59% respectively) in the earlier Pike and Sulkin data. While it would appear that clinical laboratory infection may be increasing, these increases may be due more to active employee health programs, an absence of containment equipment in some laboratories, or the fact that during the early stages of culture identification personnel are working with unknowns and not using adequate containment procedures. Similar findings to those observed by Pike and Sulkin were seen in this recent survey with respect to the number of laboratory infections associated with accidents.

More recently, workplace infections have been associated with new or emerging viruses such as human immunodeficiency virus (HIV), the etiologic agent associated with acquired immune deficiency syndrome (AIDS), and the hantavirus that causes Korean hemorrhagic fever. Herpes B virus continues to infect workers who handle certain nonhuman primates and their tissues, and an Ebola-related filovirus was associated with workplace asymptomatic seroconversions following an exposure to nonhuman primates in 1989 in Virginia (CDC, 1989). While the number of hepatitis B infections has decreased due to widespread immunization, improved work practices, and the use of engineering controls, hepatitis C virus (formerly non-A, non-B) has become a significant concern for workers because of the number of infected persons who develop chronic (long-term) infections (Mahoney et al, 1997; CDC, 1998c).

Attempts to determine incidence rates of occupationally acquired infections among laboratory personnel must be interpreted cautiously, because estimates of the number of infections and the population at risk are imprecise. Sulkin and Pike (1951) indicated that the risk of infection for researchers was six to seven times higher than for hospital and public health workers. They estimated that the annual attack rate for researchers was 4.1 per 1,000 employees (the attack rate being the number of cases divided by the population at risk). A 1971 survey of laboratory-acquired cases of tuberculosis, shigellosis, brucellosis, and hepatitis in England and Wales reported an annual incidence of 4.3 infections per 1,000 medical laboratory workers (Harrington & Shannon, 1976). A 1988 survey of laboratory-associated infections and injuries among public health and hospital clinical laboratory employees estimated the annual incidence rate for full time equivalent (FTE) employees to be 1.4 infections per thousand for public health and 3.5 infections per thousand for hospital laboratories, whereas rates for those working directly with infectious agents were 2.7 and 4.0 per thousand for public health and hospital laboratories, respectively (Vesley & Hartmann, 1988). Another study showed an estimated annual incidence rate for clinical laboratories of 3.0 infections per 1,000 employed and 9.4 infections per 1,000 when only microbiologists were considered (Jacobson et al, 1985). A recent Japanese survey of clinical laboratory workers revealed an annual incidence rate of 2.0 infections per 1,000 workers (Masuda & Isokawa, 1991).

Despite the admitted flaws in the existing data and the fact that much of the information on work-associated infections focuses specifically on laboratory-associated infections, it seems reasonable to accept the fact that some workers handling infectious materials will become infected. Epidemiological data provide the information necessary to make decisions regarding prevention or minimization of work-related infections. Accurate estimates of and surveillance for occupationally-associated infections are lacking because reports of infections usually do not include occupational data. A report of proportionate mortality from pulmonary tuberculosis as associated with occupation reflects a new effort to identify the potential for exposure (CDC, 1995). Ideally, though, infections rather than death should have been used to identify the risk of exposure in certain workplaces. For additional information on laboratory-associated infections, see Sewell, 1995 and Collins & Kennedy, 1999.

Potentially Hazardous Workplaces

Although most pathogenic microorganisms have the potential to cause occupationally acquired infections, knowledge of the hazard, containment practices, and preventive therapeutic measures such as use of vaccines greatly reduce their incidence. In workplaces where awareness of the hazard is high and the potential risk is understood, compliance with control practices minimizes exposure. However, there are some workplaces where controls are difficult to implement or are not readily available and where hazard recognition of the potential for work-associated infections is low, for example, agricultural environments and processing facilities. Workers in these environments may be exposed to potentially infectious microorganisms that are intrinsically associated with

some of the animals or plants. Controls and barriers become challenging to implement in these environments.

Because workplaces are varied and microbial habitats diverse, it can be difficult to find concise, detailed information on microbial agents. The American Public Health Association publication *Control of Communicable Diseases Manual* is an excellent resource for information on a disease, the infectious agent, its occurrence, reservoir, mode of transmission, incubation period, and methods of control (Chin, 2000).

The prevention of emerging infectious diseases presents an increasing problem as societal, technological, and environmental factors continue to have a dramatic effect on infectious diseases worldwide (CDC, 1998b). Modern demographic and ecologic conditions that favor the spread of infectious diseases include rapid population growth; increasing poverty and urban migration; more frequent movement across international boundaries by tourists, workers, immigrants, and refugees; alterations in habitats of animals and arthropods that transmit disease; increasing numbers of persons with impaired host defenses; and changes in the way food is processed and distributed. As research, clinical, and public health laboratories respond to the disease problems of the 21st century, workers will handle microorganisms that are increasingly resistant to antimicrobials (such as *Staphylococcus aureus*, *M. tuberculosis*, *Enterococcus* spp). Food and waterborne diseases (hepatitis A virus, *E. coli* 0157:H7, *Cryptosporidium* spp) and vector-borne and zoonotic diseases including disease not previously known to infect humans (Asian flu virus-Hong Kong, a new variant of Creutzfeldt-Jakob disease—bovine spongiform encephalopathy [BSE], hemorrhagic fevers) will continue to infect developing as well as developed countries.

MICROBIOLOGY, PUBLIC HEALTH, CLINICAL, AND MOLECULAR BIOLOGY LABORATORIES

The potential threat of occupational infection has long been recognized by microbiologists. However, new potential for exposure exists with the increasing number of non-microbiologists who work in the field of molecular biology. The previous review of laboratory-related infections summarizes experiences to date. Exposures tend to be directly related to the hazard classification of the organisms being manipulated, the potential for release of the organism during required manipulations, and the level of competency of personnel.

Staff in research laboratories, the type of workplace where the majority of laboratory-acquired infections have occurred, tend to work with more hazardous agents, including those of emerging diseases. They often handle concentrated preparations of infectious microorganisms, and some test procedures require complex manipulations. Because of inherent containment difficulties, the use of infected laboratory animals, including those taken from the wild, also increases the potential for worker exposure to infectious agents. More information on animals is covered later in this section.

Increased rates of occupational infections has also been noted among public health and clinical laboratory workers as compared to the general population (Vesley & Hartmann, 1988; Jacobson et al, 1995). A recent review of laboratory-associated infections noted an increased number of clinical lab infections being reported (Harding & Byers, 2000).

HOSPITALS AND HEALTH CARE ESTABLISHMENTS

In addition to infectious agents, health care facilities (which include physicians' and dentists' offices, blood banks, and outpatient clinics) may expose their personnel to multiple hazards including cytotoxic drugs, anesthetic gases, ethylene oxide, radiation sources, steam, injuries from lifting heavy objects, and electrical shock. Infections in hospitals can be categorized as community acquired (transmitted to either patients or workers); occupationally acquired (resulting from worker exposure); and nosocomial (hospital-acquired infections of patients).

The Joint Commission on Accreditation of Healthcare Organizations (JCAHO), the CDC guidelines for hospital infection control, the OSHA bloodborne pathogens standard, and the CDC/NIH biosafety guidelines (1999) all provide guidance concerning the control of nosocomial infections in patients and the protection of health care personnel. Because of the nature of hospital activities, nosocomial infections have become a complication of hospitalization. To prevent or reduce the incidence of such complications, infection control programs were developed and implemented in U.S. hospitals during the 1950s and 1960s. The CDC coordinates surveillance of hospital infections and recommends infection control practices and procedures.

In most instances a hospital epidemiologist (usually a physician who specializes in infectious diseases) and an infection control practitioner (often a nurse or, occasionally, a microbiologist) manage and oversee infection control activities. The prevalence of hospital infections has created a need for infection control procedures (barriers), rigorous disinfection and sterilization techniques, meticulous cleaning and waste-handling procedures, and, in some cases, special design criteria. The role of the industrial hygienist or environmental health and safety professional in hospital infection control may include assisting in the selection and testing of personal protective equipment, environmental testing in outbreak situations such as nosocomial fungal infections in oncology patients, and the design of engineering controls such as ventilation and containment systems.

Because it is not within the scope of this chapter to provide detailed material on the many topics covered here, the reader is referred to the Hospital Infection Program at the CDC in Atlanta and the JCAHO in Oakbrook Terrace, Ill., for guidelines and standards covering infection control programs and practices in the United States. For more information, two journals in the United States provide current information on hospital infection control: the *American Journal of Infection Control* from the Association of Professionals

in Infection Control (APIC) in Washington DC; and *Infection Control and Hospital Epidemiology*, the journal of the Society for Healthcare Epidemiology of America (SHEA), published by Slack, Inc., in Thorofare, NJ.

BIOTECHNOLOGY FACILITIES

With the discovery of recombinant DNA technology and the resulting advances in the field of molecular biology, many opportunities for the development of products in medicine, industry, agriculture, and environmental management are now possible. Industrial microbiology, long associated with the chemical and pharmaceutical industries, has attained a position of prominence with the advent of "the age of biotechnology."

From the early stages of discovery to the ultimate marketing of a pharmaceutical, large volumes of material, whether it be a metabolite or an organism, are required. Depending on the hazard level (pathogenicity or biological activity), an increase in the production or concentration of a material brings with it the need for adequate barriers to protect personnel, the product, and the community.

With some exceptions, the microorganisms most often used in manufacturing operations are those requiring minimum containment, such as genetically engineered bacteria (*E. coli* K12), fungi, plant and animal cells. Production operations usually involve the use of closed systems (either a primary container or a combination of primary and secondary containers) and validated inactivation of waste materials and contaminated by-products.

In addition to the possibility of experiencing the direct effects of the biological activity of an agent, workers may develop allergies to proteins (that is, biological products that are derived from raw materials, fermentation products, or enzymes), other chemicals, or animal dander, aerosolized urine, or other matter from animals. Allergic responses following exposure to proteins in the work environment can produce significant health effects, but they are not addressed here. For additional information on allergic response and safety issues in biotechnology, consult Nellis and Van Houten, 1995; Ducatman and Liberman, 1991; Cottam, 1994; AIHA, 1995.

ANIMAL FACILITIES AND VETERINARY PRACTICES

Although generally only work activities in research, medical, and industrial facilities involve handling laboratory animals, there are a wide range of occupations in which workers are exposed to animal-related allergens and to infectious agents or their toxins. Agricultural workers, veterinarians, workers in zoos and museums, taxidermists, and workers in animal product-processing facilities are all at risk for occupational exposure to animal-related biological hazards. A number of these workers may be exposed to wild (captured) or exotic animal populations. Factors to be considered when handling animals include the nature of the animal (its aggressiveness and tendency to bite or scratch), the normal flora and natural ecto- and endoparasites of the animal, the zoonotic diseases to which it is susceptible, and the possible dissemination of allergens.

The development of laboratory animal allergy (LAA) is a significant and common problem for laboratory personnel, veterinarians, and others who work with animals (Hunskaar & Fosse, 1990; Merchant et al, 1994; Sjöstedt et al, 1995). The manifestations of LAA include cough, wheezing (asthma), watery and itchy eyes, itchy skin, sneezing, and skin rash. Following contact with animals, symptoms can develop in less than one year, but may take up to several years to develop. Often, workers react to the proteins in shed animal dander and hair or to those in animal urine, serum, saliva, or tissues. Aerosolized mold spores and proteins from animal food and bedding can also act as allergens. The prevalence in Europe and the United States of LAA among lab workers and animal handlers has been reported to range between 11 and 44 percent (Sjöstedt et al, 1995). Specific equipment is available to reduce exposures to animal fur and dander, such as electric shavers with built-in vacuum attachments (Fisher et al, 1998).

During the past 50 years, diseases that affect both humans and animals (zoonotic diseases) have been among the most commonly reported occupational illnesses of laboratory workers. Most of these have been caused by viral and bacterial (including rickettsial) agents.

Infection is most often the result of one of the following types of exposure:

- ➢ Animal bites or scratches
- ➢ Contaminated needles, scalpels, or other inanimate objects
- ➢ Infectious aerosols resulting from animal respiration or excretion, or dust from infectious materials such as bedding
- ➢ Contact with infected tissue and cells during histological procedures, homogenization, or manipulation of cells in culture

Zoonotic infections among veterinarians are common. Several excellent references listing zoonotic diseases of laboratory animals and zoonotic pathogens causing diseases in man have been published (Fox & Lipman, 1991; National Research Council, 1989, pp 175–186; Constantine, 1998; Merchant et al, 1994, pp 688–693).

Animal-related infections can be expected at certain kinds of worksites. The infections frequently observed among personnel involve microorganisms with a low infectious dose (ID) where exposure results from aerosolized infectious materials. Numerous accounts of *C. burnetii*, the rickettsial agent that causes Q fever, have been reported. *C. burnetii* has an estimated $ID^{25\text{-}50}$ of 10 organisms by inhalation (Wedum et al, 1972). This means that 25 to 50 percent of a population becomes infected after inhaling only 10 *C. burnetii* bacteria. Many hospital and laboratory personnel have been exposed to *C. burnetii* as the result of research involving naturally infected asymptomatic sheep. In addition to being extremely

infectious, the organism is very resistant to drying and remains viable for long periods of time. Q fever control measures for research facilities using sheep were published in 1982 (Bernard et al, 1982).

Hantavirus, the etiologic agent of Korean hemorrhagic fever, produces an asymptomatic infection in wild rodents. In the past twenty years, at least 169 work-related hantavirus infections (Harding & Byers, 2000), apparently resulting from inhalation of aerosols produced by chronically infected laboratory animals, were reported in the scientific literature (Desmyter et al, 1983; Lee & Johnson, 1982; Lloyd & Jones, 1986; Wong et al, 1988). In the 1990s a unique hantavirus, the sin nombre virus (SNV), was detected in the southwestern United States. Reports of a pulmonary illness (HPS) caused by SNV underscore the infectious potential of this zoonotic agent (CDC, 1993d). Cases continue to be reported from throughout the United States and abroad now that the virus has been identified. Refer also to Weigler (1995) for a review of zoonotic hantaviruses in the United States.

Work-acquired infections contracted while handling nonhuman primates have been a concern for many years. Serious health consequences, including hemorrhagic disease and death, have resulted from Marburg virus (a human filovirus) infections in Europe (Martini & Siegert, 1971) and Ebola and Marburg viruses in Africa (WHO, 1978; Baron et al, 1983; Gear et al, 1975).

Ebola-related filovirus seroconversion was documented among several animal handlers in U.S. primate facilities (CDC, 1990b, p 221). No evidence of clinical disease was detected, but these events warrant close scrutiny of nonhuman primate colonies. Guidelines for handling nonhuman primates during transit and quarantine have been published (CDC, 1990b, pp 22–30).

At least 50 cases of *Herpesvirus simiae* (*Cercopithecine herpesvirus* or B virus) infections have been documented, most with lethal or serious outcomes (CDC-NIH, 1999). In all instances exposure was related to activities involving macaques. Fifteen infections occurred between 1979 and 1999 (Harding & Byers, 2000) and in 1987 the CDC published guidelines for prevention of *Herpesvirus simiae* (B virus) infection in monkey handlers (CDC, 1987a).

Significant similarities between the simian immunodeficiency virus (SIV) and HIV have led to the development of guidelines to prevent simian immunodeficiency virus infection in laboratory workers and animal handlers (CDC, 1988). While no illnesses has been noted in workers to date, seroconversions (one of them persistent) have been reported (CDC, 1992).

Certainly not all agents associated with zoonotic disease carry the same potential for occupational exposure as some of those described above. Nevertheless, it is critical to evaluate the risk and to determine the control measures necessary to contain the hazard before initiating work with potentially infectious or experimentally infected animals.

Agriculture

Agriculture, mining, and construction were considered to be among the most hazardous occupations of the 20th century. Agricultural workers and those who process agricultural products are exposed to numerous safety and physical hazards as well as chemical and biological agents. Workers are readily exposed to infectious microorganisms as well as their spores and toxins through inhalation, ingestion resulting from contact with contaminated materials, direct exposure of non-intact skin and mucous membranes, and inoculation resulting from traumatic injury. Factors such as host susceptibility, virulence of the agent, dose and exposure route all influence the potential for disease development.

Biological agents associated with fungal diseases (such as coccidioidomycosis, histoplasmosis, and blastomycosis) are found on plants and animals and in soils. These agents cause endemic disease and, as occupational hazards, affect primarily farmers and horticultural workers. Food and grain handlers, farmers, and laborers are exposed to parasitic diseases such as echinococcosis and toxoplasmosis. Processors who handle animal products may acquire bacterial skin diseases such as anthrax from working with contaminated hides, tularemia from skinning and dressing infected animals, and erysipelas from skin abrasions infected during contact with contaminated fish, shellfish, meat, or poultry. Infected turkeys, geese, squab, and ducks or the aerosolized feces from these birds expose poultry processing workers and farmers to psittacosis, a bacterial infection caused by *Chlamydia psittaci*.

At least 24 out of the 150 zoonotic diseases known worldwide are considered to be a hazard for agricultural workers in North America (Donham, 1985; Constantine, 1998, Merchant, 1994; Merchant et al, 1994; Acha & Szyfres, 1980). These diseases can be contracted directly from animals, but more often they are acquired in the work environment. Risk of infection varies with the type and species of animal and geographic location. Controls include awareness of specific hazards, use of personal protective equipment (PPE), preventive veterinary care, worker education, and medical monitoring or prophylactic therapy, where appropriate.

There is an extensive literature on occupational exposure of agricultural workers. For additional information, the reader is referred to Macher & Rosenberg, 1999; Popendorf & Donham (1991); AIHA (1995); and the 1986 Agricultural Respiratory Hazards Education Series published by the American Lung Association.

Miscellaneous Worksites

The potential for exposure to occupational biohazards exists in most work environments. The following list, though incomplete, cites many of the diverse workplaces where the potential for exposure to biohazardous agents exists, along with the diseases or agents to which workers may be exposed. For additional references of infectious dis-

eases by occupations see Macher & Rosenberg, 1999, pp 291–295; Dutkiewicz et al, 1988, pp 612–615; Cohen, 1997.

- ➢ Workers maintaining water systems: *Legionella pneumophila* and *Naegleria* spp.
- ➢ Workers associated with birds (such as parrots, parakeets, and pigeons) in pet shops, aviaries, zoos with avian exhibits, or on construction and public works jobs near perching or nesting sites: *Chlamydia psittaci*, *Histoplasma capsulatum.*
- ➢ Workers in wood-processing facilities: wood dust, endotoxins, allergenic fungi growing on timber, and fungi that cause deep mycoses.
- ➢ Miners: zoonotic bacteria, mycobacteria, dermatophytic fungi, fungi causing deep mycoses, mycotoxin-producing fungi. (Miners may be immunocomprornised because of exposure to coal dust, which results in black lung disease.)
- ➢ Sewage and compost workers: enteric bacteria and other infectious bacteria, endotoxin, hepatitis A virus, parasitic protozoa such as *Giardia* spp, allergenic fungi.
- ➢ Renovators of items such as books, buildings, and paintings; librarians: endotoxin, allergenic microorganisms and toxigenic fungi growing on surfaces.
- ➢ Workers in textile manufacturing who process plant fibers (such as cotton, flax, hemp): organic dust, endotoxin.
- ➢ Workers in the fishing industry: zoonotic bacteria (such as *Leptospira interrogans*, *Erysipelothrix rhusiopathiae*, and *Mycobacterium marinum*) and parasitic flukes (such as *Schistosoma* spp).
- ➢ Forestry workers: zoonotic diseases or agents (such as rabies virus, Russian spring summer fever virus, Rocky Mountain spotted fever, Lyme disease, and tularemia), viruses and bacteria transmitted by ixodid ticks, and fungi that cause deep mycoses.
- ➢ Workers who handle animal hair and rough leather: zoonotic diseases (such as Q fever, anthrax, and tularemia) and dermatophytic fungi.
- ➢ Workers who handle products of plant origin: endotoxin, allergenic actinomycetes, allergenic or mycotoxin-producing storage fungi, allergenic or toxic substances of plant origin, and allergenic storage mites.
- ➢ Child care workers: bacterial enteric diseases (*Campylobacter*, shigellosis), viruses (hepatitis A, chickenpox, measles), dermatophycoses, and protozoal diseases (cryptosporidiosis and Giardiasis).
- ➢ Public safety workers: bloodborne pathogens (hepatitis B and C viruses), viral respiratory diseases including influenza.

RISK ASSESSMENT

In the late 19th century, as scientists became aware of the presence of microorganisms and their potential to cause illness, many microbiologists suffered significant health consequences as a result of their work. Diseases such as cholera, typhus, yellow fever, Rocky Mountain spotted fever, and tuberculosis claimed the lives of those dedicated to studying or eradicating these diseases. Health care and agricultural workers suffered ongoing exposure to biological hazards before advances in medical science and animal husbandry could reduce the consequences of infectious diseases.

As has been previously stated it is possible to work with infectious agents (or people, animals, or substances infected or contaminated by them) and still avoid exposure and subsequent infection or illness. Infections do not necessarily occur simply because the exposed person works with a disease-producing agent or substance. A series of circumstances are necessary for an exposure to lead to infection or illness. By performing a risk assessment on an operation or event, it is possible to make a systematic evaluation of the exposure potential, and then to make decisions as to how the exposure can best be avoided, reduced, or otherwise managed.

Factors Affecting Infection and Exposure

The following factors can affect the type of infection and exposure that workers encounter. They will be covered in the next section.

MODES OF TRANSMISSION

The principal modes of transmission for infectious microorganisms and other biological materials include contact transmission (direct or indirect), vector-borne transmission, and airborne transmission. Direct contact of an infected person with another person is rare in the laboratory environment, but such transmission occurs commonly in the community and in medical settings where patients are treated. Animal-to-human (zoonotic) transmission through bites and scratches can occur when animals are associated with work activities. Spills or splashes of infectious materials (gross contamination) onto a receptive site such as an open wound, cut, eczematous skin, or mucous membranes are an effective means of transmitting microorganisms. Indirect transmission occurs when common environmental surfaces (such as equipment, work benches, or laboratory accessories) become contaminated, and the infectious material is transferred to a host.

Vector-borne infection results when a causative agent is transmitted to a host mechanically or biologically by a living vector (such as a mosquito or tick) through a bite, directly through the skin in rare cases, or by mechanical means. Biological transmission involves propagation, multiplication, cyclic development, or a combination of these in the host before the arthropod can transmit the infective form of the agent. Infected ticks and mosquitoes have transmitted Rocky Mountain spotted fever, malaria, and yellow fever to investigators in the laboratory and in the field and are a potential hazard for other outdoor workers.

The inhalation of airborne infectious particles into the respiratory system constitutes airborne transmission. This mode is important in the transmission of certain pathogens such as *M. tuberculosis*. The contaminated air in a room may escape to the outside and act as a conduit for contamination of the environment. Additional information on airborne transmission can be found later in this section of the chapter, under the heading "Aerosols".

ROUTES OF ENTRY

The routes of entry for microorganisms associated with occupationally-acquired infection include inhalation, ingestion, penetration through skin (intact or non-intact), and contact with the mucous membranes of the eyes, nose, and mouth. Many technical procedures (such as pressurizing liquids, sonicating, and grinding or sawing infectious materials), equipment, and spills in the workplace release microbes into the air, where workers can inhale them.

Ingestion of infectious materials can occur when workers mouth-pipet or suction infectious materials or by hand-to-mouth contamination as the result of eating, drinking, smoking, or applying cosmetics in contaminated work areas. Hand-washing minimizes the opportunity for oral and ocular exposure.

Infectious agents are introduced into the body when contaminated objects (such as hypodermic needles, broken glassware, scalpels, and other tools) or animals puncture, cut, or scratch the skin (percutaneous exposure). This type of exposure also occurs through skin surfaces that are not intact, that is, when open wounds, cuts, hangnails, dermatitis, or eczema are present. Unbroken skin is a barrier to infectious agents. Exceptions occur only in instances where skin penetration is the normal route of entry for an agent, such as with the infective cercariae stage of the parasitic agent *Schistosoma* spp.

The mucous membranes of the eyes, nose, and mouth are readily exposed to agents when rubbed with contaminated fingers or gloved hands and when splashes or sprays of infectious material occur. There have been reports of HIV and *Trypanosoma cruzi* infections related to splashes of the eyes and mucous membranes (Ippolito et al, 1999; Herwaldt & Juranek, 1995).

INFECTIOUS DOSE

The infectious, or infective, dose is the number of microorganisms required to initiate an infection. Although there are data available from animal studies on ID^{50} (the number of organisms needed to infect 50 percent of a test population), only a modest amount of information exists for humans. Data accumulated by the NIH on route of entry and infectious dose are shown in Tables 14–A and 14–B (Wedum et al, 1972).

Table 14–A. ***Infectious Dose for 25 to 50 Percent of Volunteers***

Disease or Agent	*Inoculation Route*	*Dose**
Scrub typhus	Intradermal	3
Q fever	Inhalation	10
Tularemia	Inhalation	10
Malaria	Intravenous	10
Syphilis	Intradermal	57
Shigella flexneri	Ingestion	180
Anthrax	Inhalation	≥1,300
Typhoid fever	Ingestion	10^5
Cholera	Ingestion	10^8
Escherichia coli	Ingestion	10^8
Shigellosis	Ingestion	10^9

* Dose given in number of organisms.

Adapted from Wedum et al, 1972, p 1558.

AGENT VIABILITY AND VIRULENCE

The viability and virulence of an agent are also important in determining whether a person becomes infected. If a microorganism is not viable and able to replicate, the opportunity for infection does not exist. The external environment is critical in the replication of microorganisms. Factors such as temperature, humidity, and the presence or absence of growth factors or other chemicals all play an important role in viability. For example, some bacterial agents, such as *Bacillus anthracis*, are capable of producing spores that survive under adverse conditions, and agents such as *M. tuberculosis* or *S. aureus* are unaffected by drying and remain viable on environmental surfaces, whereas other agents such as the herpes viruses are very susceptible to drying.

The virulence, or relative pathogenicity, of microorganisms varies greatly among types and strains. Some microbes are highly pathogenic, even in healthy adults, whereas others are opportunistic pathogens, able to infect only hosts with lowered immunity or sites other than their normal habitat. Some microbial strains are attenuated, or weakened, after reproducing through numerous generations in the laboratory. Certain vaccine strains, selected because they are immunogenic and do not produce significant disease, are also examples of attenuated organisms. Even though the vaccine strain of an organism may be attenuated, it is best to limit exposure to planned circumstances such as vaccination rather than by an accidental, work-related exposure.

HOST SUSCEPTIBILITY

Host susceptibility is often underestimated because the majority of persons working with potentially infectious material are healthy. The risk assessments and biosafety levels recommended by the CDC and NIH presume a population of immunocompetent workers (CDC/NIH, 1999). Employees working with infectious agents can be put at increased risk of infection because of a variety of medical conditions such as diseases, allergies, inability to receive particular vaccines, and pregnancy or by taking drugs that alter host defenses.

Table 14–B. ***Minimal Human Infective Dose in Volunteers***

Viral Agent	*Inoculation Route*	*Dose**
Measles virus	Intranasal spray	0.2**
Rhinovirus	Nasal drops	≤1
Venezuelan encephalitis virus	Subcutaneous	1†
West Nile fever virus	Intramuscular	1††
Parainfluenza 1 virus	Nasal drops	≤1.5
Poliovirus 1	Ingestion	2**§
Rubella virus	Pharyngeal spray	≤10**
Coxsackie A21 virus	Inhalation	≤18
Rubella virus	Subcutaneous	30**
Adenovirus 27	Conjunctival swab	≤32
Rubella virus	Nasal drops	60**
Adenovirus 7	Nasal drops	≤150
Respiratory syncytial virus	Intranasal spray	≤160–640
Influenza A2 virus	Nasopharyngeal	≤790
SV-40 virus	Nasopharyngeal	10,000

Note: There was illness after all inoculations except poliovirus, rubella virus (nasal drops), adenovirus (nasal drops), and SV-40 virus; in these four there were serologic conversions.

* Median infectious tissue culture dose.

** Children.

† Guinea pig infective unit.

†† Mouse infective unit.

§ Plaque-forming unit.

Adapted from Wedum et al, 1972, p 1,558.

Conditions that alter host defenses at body surfaces or impair the functioning of the immune system may put a worker at risk for certain infections. Skin disorders such as chronic dermatitis, eczema, and psoriasis leave a worker without an intact skin barrier against infection. The gastrointestinal mucosa, colonized by a resident population of normal bacterial flora, offers protection against infection by pathogenic microorganisms. However, this protection is usually disrupted when antibiotic therapy is administered. The body's immune system, consisting mainly of antibody-mediated B-cells, cell-mediated T-cells, and phagocytic cells, offers a significant line of defense against invading microorganisms (Ammann, 1987).

Women who are pregnant or intend to become pregnant are at risk of exposure to certain infectious agents, as well as other potentially hazardous materials in their work environment. Foremost among the infectious hazards is the potential for congenital infection of the fetus, due to exposure to cytomegalovirus (CMV), rubella, hepatitis B virus (HBV), herpes simplex virus, varicella virus, syphilis, or toxoplasmosis (Sheretz & Hampton, 1986).

The development of allergies to proteins (such as biological products from raw plant and animal materials, fermentation products or enzymes, chemicals, animal dander, or aerosolized animal urine proteins) also presents a risk to employees. If an employee cannot be immunized because of an allergy to a constituent of a vaccine, the safety of that person may be compromised. A higher level of work practices and personal protective equipment may provide the required level of protection for such a worker. All of these factors must be recognized and evaluated in relation to an employee's potential exposure. Decisions should be made on a case-by-case basis, with input from the employee, the employee's physician, institutional management, and an occupational health service professional (Goldman, 1995). All activities or actions associated with worker health or medical surveillance must be performed in such a manner, so that their confidentiality is not compromised. The results of medical testing or evaluation may only be released with the worker's permission.

Other Factors

Additional factors associated with risk assessment of microbial work include the ability to tolerate prophylactic or therapeutic measures (vaccines and effective interventions), knowledge of the host range of the microorganism, and an understanding of the organism's potential for escape to the community. The importance of assessing the work activity (including the facility, contamination potential, volume of material, and the agent concentration) in relation to the host and agent cannot be overemphasized.

AEROSOLS—A SPECIAL FACTOR

As noted earlier, Pike's survey of laboratory-associated infections indicated that only 18 percent of the documented infections had resulted from known accidents (Pike, 1976). For the remaining 82 percent, a connection between the infected person and the causative agent was difficult to determine. In many instances, all that is known is that the person worked with or was in the vicinity of work being done with the causative agent. The fact that no specific event could be associated with so many infections led earlier reviewers to implicate many routine laboratory procedures as the source of airborne contamination. Workers are exposed to airborne microorganisms through direct contact with or inhalation of minute airborne particles or by contact following the deposition of droplets, through splashing or spilling, onto surfaces, equipment, and personnel. Contamination as the result of splashing and spilling can also occur through transmission routes other than inhalation.

Liquid, when under pressure and passed through a small opening or when dropped onto a solid surface, is aerosolized into a cloud of very small droplets. The droplets vary in size; the larger ones settle quickly onto surfaces, inanimate objects, clothing, and skin, whereas the water in smaller particles evaporates rapidly. Bacteria and other material in the droplets remain in a dried state as droplet nuclei. These particles, or droplet nuclei, can remain suspended in air for some time and be moved to remote areas by air currents or ventilation systems.

Laboratory procedures involving the manipulation of infectious materials generate infectious particles of various sizes. For example, particles released by opening or dropping lyophilized cultures are ~ 10 μm in diameter, and particles generated by mixing, sonicating, or blending cultures range from 2–5 μm, depending on the operation (Kenny & Sabel, 1968; Reitman & Wedum, 1956). It has been shown that particles <5 μm in diameter are most effective in producing respiratory infection in animals (Hatch, 1961). See Chapter 2, The Lungs, and Chapter 8, Particulates, for additional aerosol information.

Infectious airborne particles can be generated not only from aerosolized liquids but also from lyophilized cultures, dried bacterial colonies, dried material on stoppers and caps of culture tubes and bottles, dried exudates, fungal and actinomycete spores released when cultures are opened or contaminated material is disturbed, and dusts from animals. Diseases documented to have been associated with airborne infection in the laboratory and other workplaces as well as in the community include tuberculosis, psittacosis, Q fever, pulmonary mycoses, influenza, measles, legionnaires' disease, Pontiac fever, HPS, and, in special circumstances, brucellosis, rabies, and plague.

The use of epidemiological tools to study workplace infections confirms the observation that people whose work brings them into contact with pathogenic microorganisms are at greater risk of infection than the general population. However, the mere presence of an agent does not necessarily lead to occupational exposure and infection. Certain conditions—the multiple interrelated factors of route of entry, dose, viability, virulence, mode of transmission, and host susceptibility—must be present before an infection occurs. For an infection to occur, the agent must be pathogenic and viable, present in sufficient numbers to produce infection, and be transmitted successfully and delivered to a susceptible host at a suitable entry site. It may be possible to reduce or eliminate susceptible hosts through immunization.

HAZARD CLASSIFICATION

Biological agents are not all equally dangerous to workers. An understanding of the potential for the hazardous agent to cause human disease, known as its pathogenicity, and through what routes of infection the agent is efficiently delivered to a worker permits one to develop a classification based on risk.

Hazard Categories

The following section covers biosafety containment levels, guidelines, and the interpretation of the guidelines.

BIOSAFETY CONTAINMENT LEVELS—BACKGROUND

In the 1970s, the CDC classified etiologic agents on the basis of hazard (CDC, 1974). The list compiled for that purpose still exists in slightly modified form in some government documents, including a document describing interstate shipment of etiologic agents (CDC, 1980). For appropriate identification of the categories to be used in packaging, labeling, and shipping etiologic agents, lists were provided by the CDC in 1974 and in 42 *CFR* Part 72 (CDC, 1980). The 1974 list came to be used as a classification scheme in which an organism, genus, or group of microorganisms can be categorized into a specific hazard group by users and other federal agencies. The 1980 list identified organisms that were required to be sent by registered mail. At the present time, etiologic agents and other infectious materials are considered hazardous materials under the U.S. Department of Transportation (U.S. DOT) 49 *CFR* Parts 171-180, although they are not included as hazardous agents under the OSHA hazard communication standard. The U.S. DOT inclusion and the OSHA hazard communication MSDS (material safety data sheet) exemptions cause some confusion. Obviously, information similar to that found in certain sections of an MSDS is needed to allow appropriate spill cleanup and to alleviate inappropriate public perception of risk for any shipment of microorganisms. On the other hand, if the organism being shipped is not pathogenic, there should be a mechanism for declaring an exemption from the U.S. DOT list so as not to restrict packaging to the small size limitations required for infectious substances.

Lists currently in use should be reviewed at least annually and updated accordingly because of numerous taxonomic changes and the recognition that any species of organism may have avirulent and virulent strains. Information on the more commonly recognized human pathogens can be found in peer-reviewed scientific literature and in numerous microbiology textbooks. Unfortunately, it is rare to find an assessment of the level of risk or any directives regarding the containment to be used in working with pathogens in such references. However, if the agent is listed in one of the guidelines, the first estimation of its biosafety containment level can be ascertained (OSHA, 1991; NIH, 1999; CDC/NIH, 1999; U.S. PHS, 1974).

Opportunistic microbes and normal flora that can cause disease are often inferred to be at the same risk level as a frank pathogen, because the case reports in the literature do not routinely account for host factors by differentiating between an immunocompromised host and a healthy one. Organisms that cause infections in immunocompromised adults should be evaluated to determine whether they pose a risk to healthy adults as well. Organisms that have been attenuated to make live vaccines may no longer require the same containment level as their wild-type, parent organism (*Official Journal of the European Communities*; 1990, Annex VI). For example, BCG (an attenuated strain of *Mycobacterium bovis* that may confer immunity against TB) is handled at biosafety level 2 (BSL-2), which is less restrictive than BSL-3, the level at which its parent organism, *M. bovis*,

is classified (CDC, unpublished data, 1994). Influenza vaccine strains are handled at BSL-1, whereas the parent virus is BSL-2 (CDC, 1974). The CDC Center for Infectious Diseases, Bacterial and Mycotic Diseases Branch (or other branches as appropriate) should be able to provide information on human pathogenicity of microbial agents.

Poliovirus vaccine that is given orally to children and adults was previously considered to be safely handled at BSL-1, and the wild-type strains of polio were handled at BSL-2. There are two vaccines that afford protection against all three types of poliovirus. Because of the effectiveness of the vaccines and because there is no reservoir for the virus other than humans, there is an ongoing international program to eradicate the disease. If the eradication program is successful, the BSL level for polioviruses will be reassigned. Polioviruses from any and all sources are now considered more hazardous than previously thought. The World Health Organization (WHO) has recommended a program to destroy stocks of poliovirus. Early in 2000, the poliovirus was to be handled at BSL 2/polio, a special containment designation. The WHO has indicated that poliovirus will eventually become a Risk Group 4 agent to be handled under BSL 4 conditions (WHO, 1998, 1999).

After an estimated biosafety containment level for a microbial agent is provided to the appropriate supervisor, the remainder of the risk assessment involving host-environment interactions should be done by the institution (the biosafety committee or a biosafety officer).

Although not microorganisms, cell lines and primary cells in culture must be mentioned because of their potential to be contaminated with infectious agents. When assessing the potential hazard associated with cells in culture, consider the source of the cells (human, rodent, etc.), the potential for the cells to harbor viruses or mycoplasma, whether they are tumor cells or have been transformed with virus, or whether they are established lines or only recently isolated from a host (primary cells).

If allergens or chemical agents are used, appropriate precautions to prevent sensitization should be based on exposure control limits that have been established by a reputable association, as was done by the working party of the European Federation of Biotechnology (Kuenzi et al, 1985). Biosafety levels were developed for use in protection against living microorganisms that have the potential to cause infectious disease in healthy human adults; they are not usually appropriate for the control of other hazards.

PUBLISHED GUIDELINES OF CONTAINMENT LEVELS

The biosafety guidelines most commonly used in the United States for containment of biohazardous agents in the workplace are those recommended by the CDC, the NIH, and the National Research Council (NRC) (NIH, 1999; CDC/NIH, 1999; CDC, 1974; National Research Council [NRC], 1989). Other guidelines found in the literature are based on interpretations of the recommendations of these agencies (OSHA, 1991; Kent & Kubica, 1985; Kruse et al, 1991; Fleming et al, 1995; National Committee for Clinical Laboratory Standards [NCCLS], 1997; AIHA, 1995).

The CDC/NIH Guidelines for Microbiological and Biomedical Laboratories (CDC/NIH, 1999). The CDC/NIH guidelines (*Biosafety in Microbiological and Biomedical Laboratories [BMBL]*) recommend that laboratory directors establish work practices involving containment equipment and facilities in the workplace. In doing this, they must take into account interactions of the virulence of the agent, immune status of potential hosts, and the hazards of the procedure. In addition, laboratory directors are responsible for making appropriate risk assessment of agents not included among the *BMBL* agent summary statements. The director must be familiar with the subject of risk assessment regarding biological agents or seek the advice of one who has such expertise.

Although the guidelines assign the responsibility for risk evaluation to the laboratory director, no method is suggested for determining the virulence of agents. Except for agents that have caused laboratory-acquired infections or those that pose a serious hazard to healthy adults, the CDC/NIH guidelines do not account for the use of most agents. A mechanism for updating the agent summary statements in *BMBL* was proposed through publication in the *Morbidity and Mortality Weekly Report* (*MMWR*). The only agent summary statement added between 1986 and 1993 was one for the human immunodeficiency virus. Information on the epidemiology and safety recommendations for the new hantavirus sin nombre was published in a special report in 1994 (CDC, 1994b). Following the outbreak of encephalitis in horses, birds, and humans in the late summer of 1999, the West Nile virus (WNV) was identified as the causative agent. The WNV had never before been found in the Western Hemisphere. The CDC published guidelines for surveillance, prevention, and control in *Morbidity and Mortality Weekly Report* on January 21, 2000 (CDC, 2000b).

Risk management is achieved through use of practices, facilities, and equipment specified in defined biosafety containment levels. Biosafety practices are an important part of a program to manage the risk of exposure to potentially infectious agents. The general agent descriptions and applicable work environments described by the CDC and NIH in each of the biosafety levels for both small and large scale are listed below as compiled directly from the guidelines (NIH, 1991, 1994, 1999; CDC, 1974; and CDC/NIH, 1999). An addendum at the end of this chapter outlines large-scale guidelines applicable to nonrecombinant organisms.

Biosafety level 1 (BSL-1) is used for work involving defined and well-characterized strains of viable microorganisms of no known or of minimal potential hazard to laboratory personnel or the environment. This level is appropriate for high school and undergraduate college teaching and training laboratories. No special competence is required, although training in the specific procedures should be provided, and there should be supervision by a scientist with general training in microbiology or a related science. The

laboratory is not separated from general building traffic, and work is conducted on the open bench. Examples of organisms used under these conditions are *Bacillus subtilis*, *Naegleria gruberi*, and canine hepatitis virus. Much of the recombinant DNA work with *E. coli* K12 and *Saccharomyces cerevisiae* has been approved at BSL-1.

BSL-1LS is for large scale work (greater than 10 liters or production volumes). BSL-1LS is used for the agents that can be handled at BSL-1 on a small scale. Microbial agents that have been safely used for large scale industrial production for many years may qualify for good large scale practices (GLSP) status. Examples include *Lactobacillus casei*, *Penicillium camembertii*, *Saccharomyces cerevisiae*, *Cephalosporium acremonium*, *Bacillus thuringiensis*, and *Rhizobium mellioti*. The criteria for GLSP were originally developed for the European Economic Community (now known as the European Union) by the Organization for Economic Co-operation and Development (OECD) as "good industrial large scale practices" (GILSP) (Frommer et al, 1989; OECD, 1986) and were slightly revised by the NIH for acceptance and use in the United States (NIH, 1991).

Biosafety level 2 (BSL-2) is used for work with many moderate-risk agents present in the community (indigenous) and associated with human disease of varying degrees of severity. Agents are usually of moderate potential hazard to personnel and the environment. This level is appropriate for clinical, diagnostic, teaching, and other research facilities in which work is done by individuals with a level of competency equal to or greater than one would expect in a college department of microbiology. Workers must be trained in good microbiological techniques in order for the handling of these agents on the open bench to be allowed when the potential for aerosol production is low. Laboratory personnel must have specific training in handling pathogenic agents and must be directed by competent scientists. Workers must be trained in proper use of biological safety cabinets or other appropriate primary containment equipment when the risk of aerosol production is high, as in such tasks as centrifuging, grinding, homogenizing, blending, vigorously shaking or mixing, performing sonic disruption, opening containers with increased internal pressure, inoculating animals intranasally, harvesting infected tissues from animals or eggs, and harvesting human cells from tissues using a cell separator. Access to the laboratory should be limited when work is in progress. Primary hazards to workers include accidental inoculation, exposure of non-intact skin or mucous membranes, and ingestion. Examples of organisms used under BSL-2 conditions are hepatitis B virus, *Salmonella* spp, and *Toxoplasma* spp.

BSL-2LS is for large scale, in vitro work with agents that require BSL-2 containment when work is at small scale. A detailed description of the containment requirements for BSL-2L can be found in Appendix K-IV of the NIH's recombinant DNA guidelines (NIH, 1999).

Biosafety level 3 (BSL-3) is used for work with indigenous or exotic agents where the potential for infection by aerosols is real and the disease may have serious or lethal consequences. Indigenous and exotic agents vary by country, and within regions of some countries, so there must be some flexibility for assignment of containment levels. Biosafety level 3 is appropriate for clinical diagnostic microbiology work when tuberculosis or brucellosis is suspected and also for special teaching and research situations that require the handling of such agents. Partial containment equipment such as Class I or Class II biological safety cabinets is used for all manipulations of infectious material at BSL-3. There are special engineering design criteria and work practices associated with BSL-3 containment. Worker competency must equal or exceed that of college-level microbiologists, and workers must have special training in handling these potentially lethal human pathogens and infectious materials. Supervisors must be competent scientists who are experienced in working with these agents.

Primary routes of exposure of workers to BSL-3 hazards include inhalation, with relatively few infections reported as a result of accidental auto-inoculation or ingestion. The extra personal protective clothing probably serves as a reminder of the hazard level and promotes an awareness that reduces such incidents. Examples of organisms used under BSL-3 conditions are *Mycobacterium tuberculosis*, *Brucella* spp, St. Louis encephalitis virus, *Borna* virus (an exotic agent when used in the United States), and *C. burnetii*.

BSL-3LS: The detailed requirements for BSL-3LS are to be found in Appendix K-V of the NIH recombinant DNA guidelines (NIH, 1999).

Biosafety level 4 (BSL-4) is used for work with dangerous and exotic agents that pose a high individual risk of life-threatening disease. Such an agent has a low infectious dose and poses a danger for the community from person-to-person spread. BSL-4 containment is appropriate for all manipulations of potentially infectious diagnostic materials, isolates, and naturally or experimentally infected animals. Maximum containment equipment, such as a Class III biological safety cabinet, or partial containment equipment in combination with a full-body, air-supplied, positive-pressure personnel suit is used for all procedures and activities. Because of the stringent requirements associated with BSL-4 containment, only a few facilities that meet this standard have been built and are operational.

The main hazard to laboratory or animal care personnel working with agents requiring such extreme caution and containment is respiratory exposure to infectious aerosols. Mucous membrane exposure to infectious droplets and accidental parenteral inoculation also play a role in transmission of infections. Worker competency must equal or exceed that of college-level microbiologists, and workers must receive specific, thorough training in handling extremely hazardous infectious agents. They must understand the function of the primary and secondary containment equipment and the facility design. Supervisors must be competent scientists trained and experienced in such work.

Laboratory access is strictly controlled. The facility is either separated from other buildings or completely isolated from other areas of the building. A separate facility operations manual is required. The maximum containment facility has special design and engineering features that prevent dissemination of microbes to the environment. Some examples of organisms used under these conditions are the agents of viral hemorrhagic fevers (Lassa, Machupo, Marburg, and Ebola), filoviruses, and certain arboviruses.

The requirements for laboratory-scale BSL-4 are described in *BMBL* (CDC/NIH, 1999). Appendix K of the NIH recombinant guidelines (Physical containment for large scale uses of organisms) does not include a description of requirements for BSL-4L because the requirements should be determined on a case-by-case basis if they are requested.

Animal biosafety levels: Other special biosafety precautions described in these guidelines apply to the use of naturally or experimentally infected animals. Animals are restricted from the laboratory unless they are part of the experiment at BSL-2 and higher, and decorative plants are restricted from use at BSL-3 and higher. Animals and plants harbor their own microbial flora, which could infect the worker or contaminate the work, so it is prudent to prohibit their use or presence in microbiology laboratories.

There are intrinsic hazards associated with the use of certain animals (for example, from herpes B virus in macaques), which must be taken into account in assessing the risk to the worker. There are also extrinsic hazards when infectious agents are purposely used to infect animals and vector-host interactions are being studied (in vivo) as opposed to the "controlled work" in culture media (in vitro). These hazards must be addressed.

NIH Guidelines for Research Involving Recombinant DNA Molecules (NIH, 1999 and revisions). The CDC's *Classification of Etiologic Agents on the Basis of Hazard* (1974) was slightly modified and incorporated into Appendix B of the NIH guidelines. The original CDC classification system provided "points to consider" in estimating the degree of hazard, noting that it depended on the etiologic agent and its nature and use. These notes were not included in the NIH document, implying to the user that all members of the groups, species, and strains on that list were pathogenic. Because the NIH guidelines could not take into account all existing and anticipated information on special procedures, users were encouraged to recommend changes to the guidelines. For example, Appendix B has been revised and updated as can be seen in the current guidelines (NIH, 1999).

The NIH guidelines provide the same message as the CDC/NIH guidelines (*BMBL*) that the agent/product rather than the process of recombinant DNA work should be evaluated for worker safety (NRC, 1987). The basic biosafety requirements for work with all microorganisms are the same. However, nonpathogenic, genetically modified organisms are currently registered and regulated at most institutions because of the public's perception of risk, whereas work with true pathogens is often done without internal oversight and review because the public has not been made aware of the risk. For large-scale guidelines, see appendix K (NIH, 1999).

***National Research Council Guidelines* (NRC, 1987, 1989).** *Biosafety in the Laboratory: Prudent Practices for the Handling and Disposal of Infectious Materials* (NRC, 1989): To avoid exposure to infectious agents, the NRC's Committee on Hazardous Biological Substances in the Laboratory recommended seven basic prudent biosafety practices, which are listed later in the chapter. These prudent practices provide barriers against the known routes of exposure for most diseases and are the basic recommendations for working with biohazardous agents. The recommendations are supplemented with additional practices, equipment, and facility design as the severity of the hazard increases. The practices recommended by the NRC, when accompanied by recommendations for facility design and containment equipment, are compatible with the CDC and NIH biosafety levels.

***Introduction of Recombinant DNA-Engineered Organisms into the Environment: Key Issues* (NRC, 1987):** The NRC has concluded that there is no evidence of any unique hazards posed by recombinant DNA techniques. The risks associated with recombinant DNA are the same in kind as those associated with unmodified organisms or organisms modified by other means. The NRC recommended that risk assessments be based on the nature of the organism and the environment into which it is introduced, and not on the method by which it was produced. This recommendation was also accepted by the Office of Science and Technology Policy (OSTP, 1986). Given this conclusion, two sets of guidelines, one for recombinant work and another for work with human pathogens, are redundant. Guidelines for a single code of practice for protection of workers from exposure to biohazardous agents are appropriate and have already been accepted in Europe (*Official Journal of the European Communities*, 1990; OECD, 1986).

INTERPRETATION OF GUIDELINES

Using the CDC/NIH guidelines previously described, decisions on containment levels for work at BSL-1 through BSL-3 at small- and large-scale can be made at the institutional level. BSL-4, because it is limited to so very few facilities, is not considered here. The expertise of an institution's biosafety committee or biosafety officer is needed for risk assessment of pathogenic agents and infectious materials. A professional biosafety consultant may be needed for facilities that do not have such in-house expertise. (The American Biological Safety Association in Mundelein, Ill. can be contacted for a list of certified biosafety professionals.)

Risk assessment for agents to be used at large scale, especially for industrial production, should begin early as an integral part

Table 14–C. ***Summary of Recommended Biosafety Levels for Infectious Agents***

Biosafety Level	*Agents*	*Practices*	*Safety Equipment (Primary Barriers)*	*Facilities (Secondary Barriers)*
1	Not known to consistently cause disease in healthy adults	Standard microbiological practices	None required	Open bench top, sinks required
2	Associated with human disease. Hazard is from percutaneous injury, ingestion, mucous membrane exposure	BSL-1 practice plus —limited access —biohazard warning signs —sharps precautions —biosafety manual defining any needed waste decontamination or medical surveillance policies	Primary barriers - Class I or II BSCs or other physical containment devices used for all manipulations of agents that cause splashes or aerosols of infectious materials; PPEs; laboratory coats; gloves; face protection as needed	BSL-1 plus autoclave available
3	Indigenous or exotic agents with potential for aerosol transmission; disease may have serious or lethal consequences	BSL-2 practice plus —controlled access —decontamination of all waste —decontamination of lab clothing before laundering —baseline serum	Primary barriers - Class I or II BSCs or other physical containment devices used for all open manipulations of agents; PPEs; protective lab clothing; gloves; respiratory protection as needed	BSL-2 facility plus —physical separation from access corridors —self-closing, double-door access —exhausted air not recirculated —negative airflow into laboratory
4	Dangerous/exotic agents which pose high risk of life-threatening disease; aerosol-transmitted lab infections; or related agents with unknown risk of transmission	BSL-3 practices plus —clothing change before entering —shower on exit —all materials decontaminated on exit from facility	Primary barriers - All procedures conducted in Class III BSCs or Class I or II BSCs in combination with full-body, air-supplied, positive pressure personnel suit	BSL-3 facility plus —separate building or isolated zone —dedicated supply and exhaust, vacuum, and decontamination systems —other requirements outlined in the text

Source: CDC, *BMBL*, 1999, p 62.

of the research and development process. The level of pathogenicity should be determined before production of the organism is scaled up, because special large scale containment facilities are too costly to be built and maintained if they are not needed.

The Coordinated Framework for Biotechnology (Office of Science and Technology Policy, 1986) has added the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture, the Food and Drug Administration, and OSHA to the list of federal agencies such as the CDC and NIH who can provide oversight and information on risk assessment. Work with certain agents associated with terrorist activities or biological warfare may require oversight from federal defense agencies as well (Nettleman, 1991). The Department of Commerce also restricts the export of such agents/materials because of their potential use for biological warfare.

HAZARD CONTROL

The process of developing controls to prevent or minimize occupational exposure to infectious agents or other biological agents becomes straightforward once the actual risk of work with the organism or agent is known and the risk category established. Prevention of exposure to potentially infectious agents can be achieved by source control, minimization of accidental release, and protection of the worker. Containment or barriers, used along with the other components of a comprehensive biosafety program, provide the means to work with biological agents without adverse effect.

Containment

Workplace activities involving infectious or biological agents require containment so that workers, the immediate work environment, and the community including those outside the immediate workplace are protected or shielded from exposure. Facility design, safety equipment, and work practices are the building blocks of containment. Varying configurations of these components are used depending on the hazard category of the work.

Protection of workers and the immediate work environment, or primary containment, is achieved through the use of good work practices and appropriate safety equipment. Effective vaccines also decrease worker risk. Protection of personnel in the immediate area outside the laboratory and the community (environment external to the workplace), or secondary containment, is attained by using adequately designed, constructed, and maintained facilities and operational practices.

The CDC and NIH have designated the four biosafety levels (BSLs) previously outlined for work involving infec-

Table 14–D. ***Summary of Recommended Biosafety Levels for Activities in Which Experimentally or Naturally Infected Vertebrate Animals Are Used***

Animal Biosafety Level (ABSL)	*Agents*	*Practices*	*Safety Equipment (Primary Barriers)*	*Facilities (Secondary Barriers)*
1	Not known to consistently cause disease in healthy adults	Standard animal care and management practices, including appropriate medical surveillance programs	As required for normal care of each species	Standard animal facility —no recirculation of exhaust air —directional air flow recommended —handwashing sink recommended
2	Associated with human disease. Hazard: percutaneous exposure, ingestion, mucous membrane exposure	ABSL-1 practice plus —limited access —biohazard warning signs —sharps precautions —biosafety manual —decontamination of all infectious wastes and of animal cages prior to washing	ABSL-1 equipment plus primary barriers; containment equipment appropriate for animal species; PPEs; laboratory coats; gloves; face and respiratory protection as needed	ABSL-1 facility plus —autoclave available —handwashing sink available in the animal room —mechanical cage washer used
3	Indigenous or exotic agents with potential for aerosol transmission; disease may have serious health effects	ABSL-2 practice plus —controlled access —decontamination of clothing before laundering —cages decontaminated before bedding removed —disinfectant foot bath as needed	ABSL-2 equipment plus containment equipment for housing animals and cage dumping activities; Class I or II BSCs available for manipulative procedures (inoculation, necropsy) that may create infectious aerosols, PPEs; appropriate respiratory protection	ABSL-2 facility plus —physical separation from access corridors —self-closing, double-door access —sealed penetrations —sealed windows —autoclave available in facility
4	Dangerous/exotic agents which pose high risk of life-threatening disease, aerosol transmission; or related agents with unknown risk of transmission	ABSL-3 practices plus —entrance through change room where personal clothing is removed and laboratory clothing is put on; shower on exiting —all wastes are decontaminated before removal from the facility	ABSL-3 equipment plus maximum containment equipment (i.e., Class III BSC or partial containment equipment in combination with full body, air-supplied positive-pressure personnel suit) used for all procedures and activities	ABSL-3 facility plus —separate building or isolated zone —dedicated supply/exhaust, vacuum, and decontamination systems —other requirements outlined in the text

Source: CDC, *BMBL*, 1999, p 75.

tious agents or activities in which experimentally or naturally infected vertebrate animals are manipulated. Each biosafety level consists of a combination of laboratory practices and techniques, standard microbiological and special practices, safety equipment, and facility design. The combination must be specifically appropriate for the operations performed, the documented or suspected routes of transmission of the agent, and the laboratory function or activity. The use of increasingly stringent procedures and more complex laboratory facilities permits microorganisms in higher-risk categories to be handled safely. Tables 14–C and 14–D summarize the recommended biosafety levels for handling different categories of infectious agents and experimentally or naturally infected animals (CDC/NIH, 1999).

FACILITY DESIGN

The laboratory facility provides the shell, or barrier, necessary to protect the community and those outside the immediate work area from exposure to hazardous materials. When agents of increasing hazard are manipulated, facility design plays a more important role in reducing the potential for dissemination of the agent, particularly when an accidental release within the laboratory occurs.

Biosafety level-1 and -2 laboratories have no special design features beyond an ordinary laboratory, except that a handwashing sink is required, doors should be present for access control, and windows opening to the exterior must have fly screens. BSL-2 laboratories may require lockable doors for certain restricted agents and in new facilities directional air

Table 14–E. *Comparison of Biological Safety Cabinets*

Type	*Face Velocity (lfpm)*	*Airflow Pattern*	*Radionuclides/ Toxic Chemicals*	*Biosafety Level(s)*	*Product Protection*
Class I* open front	75	In at front; rear and top through HEPA filter	No	2,3	No
Class II, Type A	75	70% recirculated through HEPA; exhausted through HEPA	No	2,3	Yes
Type B1	100	30% recirculated through HEPA; exhausted through HEPA and hard ducted	Yes (low levels / low volatility)	2,3	Yes
Type B2	100	No recirculation; total exhaust through HEPA and hard ducted	Yes	2,3	Yes
Type B3		Same as IIA, but plena are under negative pressure to room and exhaust air is ducted	Yes	2,3	Yes
Class III	NA	Supply air inlets and exhaust through 2 HEPA filters	Yes	3,4	Yes

* Glove panels may be added and will increase face velocity to 150 lfpm; gloves may be added with an inlet air pressure release that will allow work with chemicals/radionuclides.
Source: CDC, *BMBL*, 1999, p 205.

flow into the laboratory is encouraged.

The WHO (1993) characterizes agents handled in BSL-1 and BSL-2 laboratories as those having no or very low individual or community risk (BSL-1) or moderate individual risk and low community risk (BSL-2); therefore, the need for special design features to protect the community does not arise in these labs.

The biosafety level-3 laboratory includes design features of BSL-1 and BSL-2 laboratories plus they must be separated from areas of unrestricted traffic flow within the building. In addition, these facilities have controlled access (double-door entry), a specialized ventilation system that creates a directional one-pass airflow into the laboratory from surrounding "clean" areas, special hand-washing controls (elbow, foot, or knee operated), and a means to decontaminate biological waste, preferably within the BSL-3 area. Microorganisms classified at risk level 3 present a high risk to individuals, usually by respiratory exposure, although risk to the community is low.

BSL-3 facility requirements impose additional expense for containment features. In some circumstances where existing facilities do not meet BSL-3 requirements or cannot be made to do so, some accommodation may be made. Work involving routine or repetitive operations (such as diagnostic procedures involving propagation of agents for identification, typing, and susceptibility testing) can be carried out in a BSL-2 facility as long as the work practices and safety equipment associated with BSL-3 containment are used. Exhaust air from the laboratory is also discharged to the outdoors and ventilation to the laboratory is balanced to provide directional air flow into the lab. The decision to alter containment conditions should only be made by the laboratory director. The publication *Biosafety in Microbiological and Biomedical Laboratories* (CDC/NIH, 1999) contains agent summary statements for most microorganisms handled at BSL-3 and identifies those agents where modification of containment conditions may be appropriate.

The biosafety level 4 facility, though rare, draws a great deal of attention, perhaps because it conjures visions of an "Andromeda strain." Agents handled in such a facility have no available vaccines and pose a high risk to both workers and the community, so design criteria must prevent both worker and community exposure. In addition to having the design components of level 3 facilities, a BSL-4 facility is housed in a separate building or in isolated zones that has dedicated ventilation, stringent access requirements, and decontamination systems. For more detailed information, see CDC/NIH (1999).

SAFETY EQUIPMENT

Because most experimental procedures are recognized as having the potential to generate aerosols, safety equipment designed to reduce the likelihood of worker and environmental exposure has become standard in biological laboratories during the last decade.

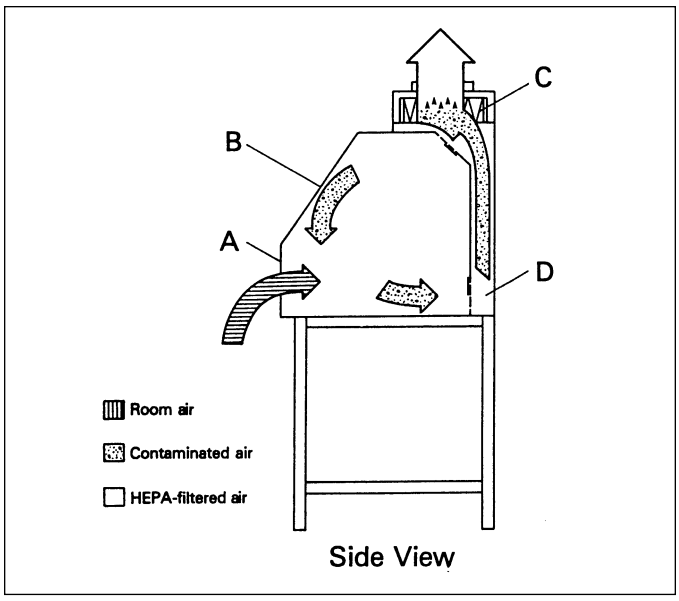

Figure 14–1. Class I biological safety cabinet. A. front-opening, B. sash, C. exhaust HEPA filter, D. exhaust plenum. (Reprinted from *Biosafety in Microbiology and Biomedical Laboratories [BMBL].* CDC, 1999, p 206.)

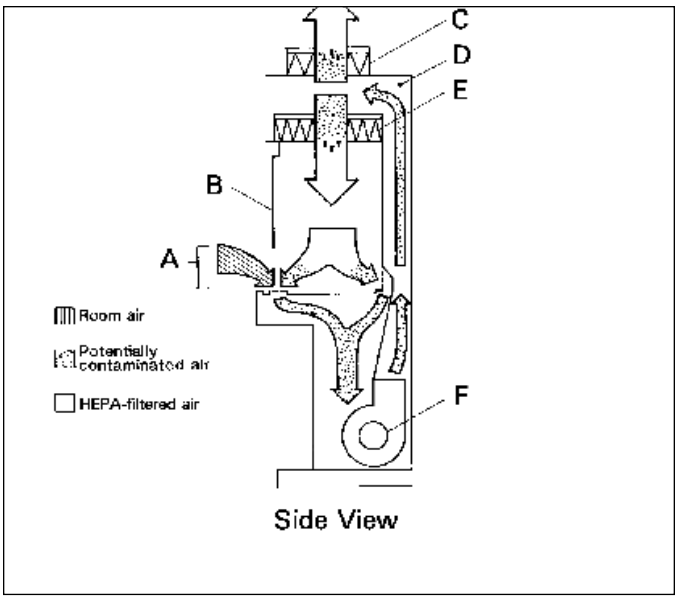

Figure 14–2a. Class II, type A biological safety cabinet. A. front opening, B. sash, C. exhaust HEPA filter, D. rear plenum, E. supply HEPA filter, F. blower. (Reprinted from *BMBL*, CDC, 1999, p 207.)

Biological safety cabinets (BSCs). The most frequently used and effective example of laboratory containment equipment is the biological safety cabinet, which provides a primary barrier to prevent escape of infectious aerosols into the work environment. When used and maintained properly these cabinets provide a combination of worker, product, and environmental protection that varies according to the class and type of cabinet selected.

All three classes of biological safety cabinets (Class I, II, and III) have high-efficiency particulate air (HEPA) filters for exhaust air. Of these, the Class II cabinet is most widely used. Selection of the class and type of cabinet must be based on the hazard level of the microorganism to be manipulated, the nature of the work activity (the potential of a technique to produce aerosols), and the need to protect the worker or the work environment from airborne contamination (see Table 14–E). Class I and II cabinets, when used in conjunction with good microbiological practices, provide an effective means to safely manipulate moderate- and high-risk microorganisms (BSL-2 and BSL-3).

Class I-ventilated cabinets provide personnel and environmental protection (not product protection) by means of a unrecirculated inward airflow away from the operator. The minimum face velocity at the work opening is at least 75 linear feet per minute (lfpm). The cabinet exhaust air is HEPA filtered to protect the environment before it is discharged either to the laboratory or through duct work to the outside atmosphere. In practice this cabinet functions in a manner similar to a chemical fume hood, except for the additional HEPA filtration of exhaust air. The use of Class I cabinets is relatively rare, although they are increasingly used to provide containment for aerosol-producing equipment (or procedures) such as centrifuges, pressurized apparatus, and necropsy of infected animals. Figure 14–1 shows the design and airflow patterns of this cabinet.

Because Class II biosafety cabinets provide protection to workers, experimental materials, and the environment and are easily accessed through a front work opening, they are often used in biological laboratories for manipulation of microorganisms and tissue cultures. Class II cabinets have a face velocity of 75–100 lfpm and are divided into types A and B, with type B cabinets designated as B1, B2, or B3 (see Figures 14–2a through d). Class II, type A cabinets may be used for microbiological activities when volatile or toxic substances and radionuclides are not used. The exhaust air from this cabinet is usually discharged to the work environment, although it may be connected to exhaust ductwork by a thimble connection. The design criteria for this cabinet permit contaminated ducts and plenums under positive pressure.

All Class II, type B cabinets are hard-ducted to the outside atmosphere and have 100 lfpm face velocity, and when contaminated plenums exist, they are under negative pressure or are surrounded by negative-pressure ducts or plenums, depending on the cabinet type. Work associated with minute or small amounts of volatile and toxic chemicals and radionuclides associated with microbiological activities may be handled in a type B cabinet. Whereas the Class II, type B1 cabinet is the basic B design, B2 and B3 have been developed to provide some useful alternatives. Because the B2 cabinet is a "total exhaust" cabinet with no air recirculation, it can be used for cell work involving small amounts of hazardous or toxic chemicals, such as carcinogens and radionuclides. The B3 cabinet, known as the

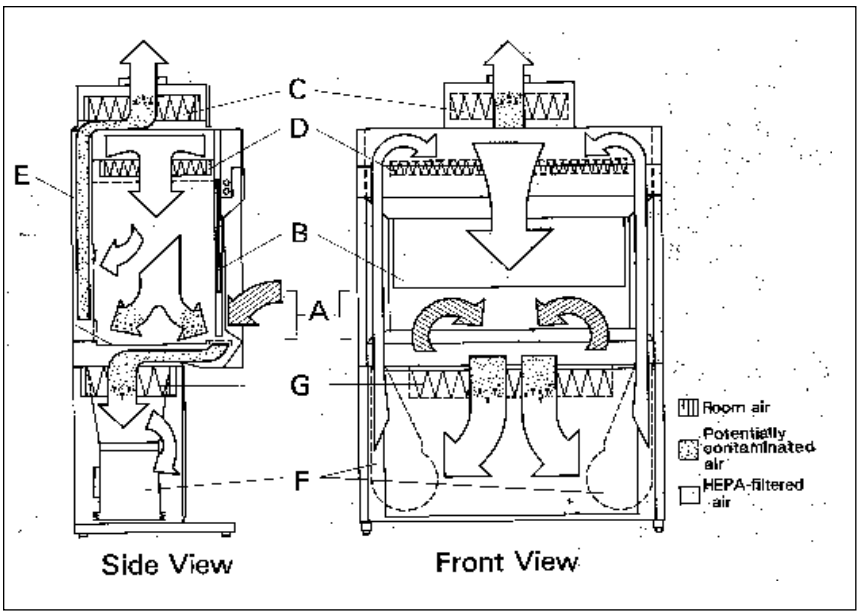

Figure 14–2b. Class II, type B1 biological safety cabinet. A. front-opening, B. sash, C. exhaust HEPA filter, D. supply HEPA filter, E. negative-pressure exhaust plenum, F. blower, G. additional HEPA filter for supply air. Note: The cabinet exhaust needs to be connected to the building exhaust system. (Reprinted from *BMBL*, CDC, 1999, p 208.)

"convertible cabinet," is basically a type A design that can be converted to meet the type B criteria.

The Class III cabinet is a totally enclosed, ventilated, negative-pressure cabinet of gas-tight construction that is used for work requiring the highest level of containment (see Figure 14–3). It offers maximum protection for personnel, the environment, and work materials. Personnel protection equivalent to that provided by the Class III cabinet can also be attained by using a positive-pressure ventilated suit in a maximum containment facility in conjunction with a Class I or II cabinet (CDC/NIH, 1999, p 203).

Certification of biosafety cabinets. The effectiveness of biological safety cabinets depends on a combination of airflow velocity, filter integrity, and location in the laboratory, because ventilation currents and even workers' movements can disrupt cabinet air patterns. It should not be assumed that equipment (or a facility) is providing worker protection merely because it is designed to do so. To be assured that a biological safety cabinet is functioning as designed, it must be certified on a regular basis (prior to initial use, when moved, after a filter change, or at least annually).

The National Sanitation Foundation Standard (NSF) #49 (NSF, 1992) for Class II (laminar-flow) biohazard cabinetry specifies materials, design and construction, and performance criteria for manufacturers. It also outlines recommended field tests for certifiers. Manufacturers must submit new models for NSF testing. Approved models carry the NSF seal. Only approved cabinets should be purchased and

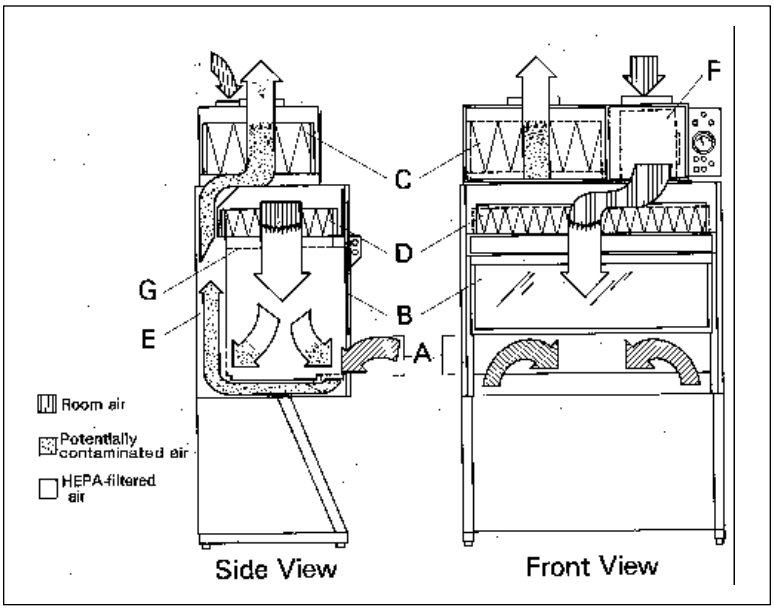

Figure 14–2c. Class II, type B2 biological safety cabinet. A. front opening, B. sash, C. exhaust HEPA filter, D. supply HEPA filter, E. negative-pressure exhaust plenum, F. filter screen. Note: The cabinet exhaust needs to be connected to the building exhaust system. (Reprinted from *BMBL*, CDC, 1999, p 209.)

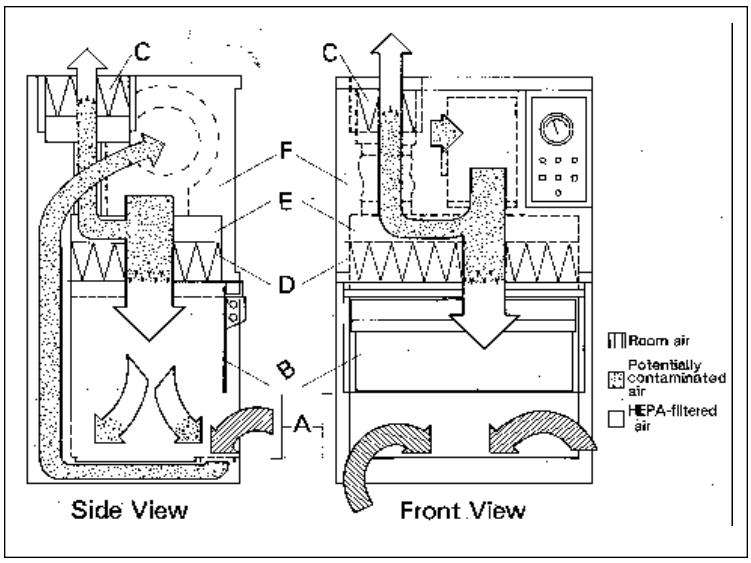

Figure 14–2d. Class II, type B3 biological safety cabinet (table-top model). A. front-opening, B. sash, C. exhaust HEPA filter, D. supply HEPA filter, E. positive-pressure plenum, F. negative-pressure plenum. Note: The cabinet exhaust needs to be connected to the building exhaust system. (Reprinted from *BMBL*, CDC, 1999, p 210.)

used for work activities involving potentially hazardous biological agents.

Even cabinets with correct design, materials, and construction, rigorous testing, and proper placement may not be enough to prevent workplace and environmental exposures. These features along with well-trained, knowledgeable, and conscientious workers are required for optimal safety conditions. Poor work practices can easily cancel the containment features designed into the cabinet, permitting the release of infectious particles into the environment. It is for this reason that worker training is so critical. The reader can find additional information on the design and use of these cabinets in a variety of excellent references (NRC, 1989; Fleming et al, 1995; Lupo, 1995; CDC/NIH, 1995; CDC/NIH, 1999; WHO, 1993).

Horizontal- or vertical-flow clean benches, which force air out of the front opening into the room, should not be confused with biosafety cabinets. They do not protect workers from exposure; they protect the work product. Therefore, clean benches must not be used for work with materials that are potentially infectious, toxic, allergenic, or irritating.

Centrifugation. Centrifugation can present two serious hazards: mechanical failure and dispersion of aerosols. A mechanical failure such as a broken drive shaft, a faulty bearing, or a damaged rotor can produce not only aerosols but also fast-moving fragments. Even when functioning correctly, a centrifuge is capable of producing hazardous aerosols if improperly operated or when poor laboratory practices are used. Mechanical failure can be minimized by routine maintenance and meticulous observance of the manufacturer's instructions. Generation of aerosols is avoided by using good work practices such as balancing containers and not overfilling them, checking containers for cracks and signs of stress, and checking and greasing O-rings where applicable. Aerosolization is minimized by placing primary containers into centrifuge safety cups and opening rotors and centrifuge containers in a biosafety cabinet.

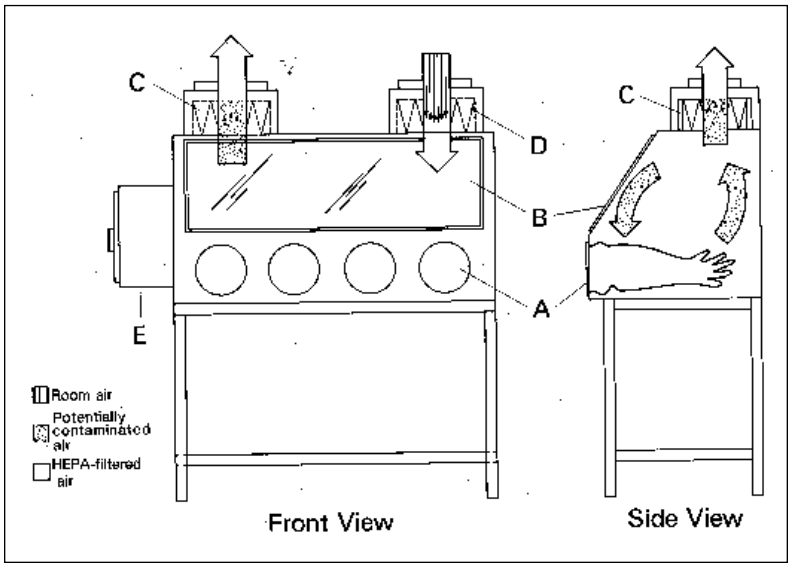

Figure 14–3. Class III biological safety cabinet. A. glove ports, with O-ring for attaching arm-length gloves to cabinet. B. sash, C. exhaust HEPA filter, D. supply HEPA filter, E. double-ended autoclave or pass-through box. Note: A chemical tank may be installed which would be located beneath the work surface of the BSC with access from above. The cabinet exhaust needs to be connected to the building exhaust system. (Reprinted from *BMBL,* CDC, 1999, p 211.)

Laboratory procedures where force or energy act on cell walls or tissue to disrupt them result in the dispersion of aerosols and splatter. Particular attention should be paid to containment when procedures such as homogenization and sonication are planned. Some manufacturers of homogenizers design models that prevent the release of infectious material and specially gasketed blenders are also available. The use of properly designed and maintained containment equipment is essential in minimizing release of infectious aerosols to the environment.

WORK PRACTICES

Work practices—how one actually does the work—are the most important component in preventing occupational exposure. Understanding the concepts of transmission, infectious dose, and route of entry, as well as the potential for various procedures to release infectious material, is critical to the implementation of appropriate containment practices. It becomes straightforward to identify the potential hazard and implement the safeguards necessary to protect workers, when a risk assessment is performed on work activities in advance.

The safeguards known as the seven basic rules of biosafety (NRC, 1989) are summarized here:

- ➢ Do not mouth pipette.
- ➢ Manipulate infectious fluids carefully to avoid spills and the production of aerosols and droplets.
- ➢ Restrict the use of needles and syringes to procedures for which there are no alternatives; use needles, syringes, and other sharps carefully to avoid self-inoculation; and dispose of sharps in leak- and puncture-resistant containers.
- ➢ Use protective laboratory coats and gloves.
- ➢ Wash hands after all laboratory activities, after removing gloves, and immediately following contact with infectious materials.
- ➢ Decontaminate work surfaces before and after use, and immediately after spills.
- ➢ Do not eat, drink, store food, apply cosmetics, or smoke in the laboratory.

Although not a complete listing, these rules represent baseline or minimum practices to be followed. They can be amplified with additional protective clothing such as goggles, full-face shields, or masks when face protection from splatter is needed, and with different types of clothing such as back-fastening gowns, jumpsuits, impervious aprons, sleeve covers, and head and foot covers as suitable. Personal habits such as nail biting and eye and nose rubbing must be avoided because they offer an excellent means for ingesting pathogens and contaminating mucous membranes. The use of good microbiological practices is critical for a worker's own protection and the protection of adjacent colleagues.

DECONTAMINATION

The protection of personnel and the environment from exposure to infectious agents and the prevention of contamination of experimental materials by a variable, persistent, and unwanted background of microorganisms is an integral part of good microbiological procedure. Decontamination, the use of physical or chemical means to render materials safe for further handling by reducing the number of organisms present, must be differentiated from disinfection, a process that kills infectious agents outside the body. Neither of these terms should be confused with sterilization, which implies complete elimination or destruction of all forms of microbial life. In the laboratory setting, the application of heat, either moist or dry, is the most effective method of sterilization. Steam at 250 F (121 C) under pressure in an autoclave is the most widely used and convenient method of rapidly achieving sterilization. However, many variables such as time, temperature, configuration and size of load, and permeability and dimensions of containers must be taken into account in order to successfully sterilize materials.

Chemical disinfectants inactivate microorganisms by one or more of a number of chemical reactions, primarily coagulation and denaturation of protein, lysis, or inactivation of an essential enzyme by either oxidation, binding, or destruction of the enzyme substrate. The level of effectiveness of chemical disinfectants is altered by changes in the concentration of active ingredients, contact duration, temperature, humidity, the concentration of organic matter, and the pH of the material being disinfected. Chemical disinfectants, classified by their active ingredients, include halogens, acids and alkalis, alcohols, heavy-metal salts, quaternary ammonium compounds, phenolics, aldehydes, ketones, and amines.

Specific terminology and classification schemes for chemical disinfectants used by the medical community and licensed by the U.S. EPA can be found in several excellent references and texts (Rutala, 1996; Garner & Favero, 1986; Block, 1991; Favero & Bond, 1991; Klein & Deforest, 1963; NAIN website).

The most frequently used disinfectants in the workplace include sodium hypochlorite (household bleach), isopropyl or ethyl alcohol, iodophors (Wescodyne), and phenolics (Lysol and amphyl). It is essential when choosing a disinfectant to review the manufacturer's literature to determine the disinfectant's efficacy (what microorganisms the disinfectant inactivates) and the recommended application (as an inanimate surface disinfectant, topical disinfectant, surgical scrub, liquid sterilant, or sanitizer). Table 14–F highlights various chemical disinfectants and their uses.

By definition, chemical disinfectants are toxic to viable cells, so it is important that users be familiar with the hazard potential of compounds they use and take necessary precautions to prevent workplace exposure. Compounds such as ethylene oxide, formaldehyde, glutaraldehydes, and concentrated acids and bases require special handling procedures. Consult federal and local OSHA regulations on specific chemical hazards.

INFECTIOUS WASTE

During the past two decades the management of infectious waste has come under scrutiny from regulatory agencies. Pub-

Table 14–F. ***Summary of Practical Disinfectants***

	Ethylene Oxide	*Paraformal-dehyde (gas)*	*Vaporized Hydrogen Peroxide*	*Quatenary Ammonium Compounds*	*Phenolic Compounds*	*Chlorine Compounds*	*Iodophor Compounds*	*Alcohol (ethyl or isopropyl)*	*Formal-dehyde (liquid)*	*Glutaral-dehyde*	*Hydrogen Peroxide (liquid)*
Use parameters											
Concentrations of active ingredients	400–800 mg\L	0.3 g/ft^3	2.4 mg/L	0.1–2%	0.2–3%	0.01–5%	0.47%	70–85%	4–8%	2%	6%
Temperature, °C	35–60	>23	4–50								
Relative humidity, %	30–60	>60	<30								
Contact time, min.	105–240	60–180	8–60	10–30	10–30	10–30	10–30	10–30	10–30	10–600	10–600
*Effective against**											
Vegetative bacteria	+	+	+	+	+	+	+	+	+	+	+
Bacterial spores	+	+	+			±			±	+	+
Lipoviruses	+	+	+	+	+	+	+	+	+	+	+
Hydrophilic viruses	+	+	+		±	+	±	±	+	+	+
Tubercle bacilli	+	+	+		+	+	+		+	+	+
HIV	+	+		+	+	+	+	+	+	+	
HBV	+	+			±	+	±	±	+	+	
*Applications**											
Contaminated liquid discard						+			±		
Contaminated glassware	±			+	+	+		+	±	+	+
Contaminated instruments	±				+				±	+	+
Equipment total decontamination	±	+	+								

*A + denotes very positive response; ±, a less positive response; and a blank, a negative response or not applicable.

Adapted from: National Research Council. *Biosafety in the Laboratory: Prudent Practices for the Handling and Disposal of Infectious Materials*. 1989, p 40; and Vesley D, Lauer JL. In *Laboratory Safety: Principles and Practices*, 1995, pp 226–227.

lic fear of exposure to AIDS and hepatitis viruses has prompted demands for implementation of rigorous controls for infectious hospital and medical wastes. Most states have promulgated what can only be described as a patchwork of infectious waste regulations. Historically, such wastes were treated by autoclaving before disposal into a sanitary landfill, by incineration, or, in the case of some liquid wastes, by chemical disinfection. Today, these technologies coupled with newer ones (grinding infectious lab wastes in the presence of chemical disinfectants or alkaline hydrolysis at elevated temperature and pressure for disposal of animal carcasses [suitable for large animals]) provide alternate options for waste generators. Local regulations should be consulted for individual state requirements. Federal regulations such as the U.S. DOT Hazardous Materials Regulations, 49 *CFR* 170 series, establish some packaging and volume limitations for the shipment of regulated medical wastes.

Because of the many misconceptions regarding hospital waste, the CDC published the following statement (CDC, 1987b):

> *There is no epidemiologic evidence that most hospital waste is any more infective than residential waste. Moreover, there is no epidemiological evidence that hospital waste has caused disease in the community as the result of improper disposal. Therefore, identifying wastes for which special precautions are indicated is largely a matter of judgment about the relative risk of disease transmission. The most practical approach to the management of infectious waste is to identify those wastes with a reasonable potential to cause infection during handling and disposal, and for which some special precautions appear prudent. Hospital wastes for which special precautions appear prudent include microbiology laboratory waste, pathology waste, and blood specimens and blood products. Although any item that has had contact with blood, exudates, or secretions may be potentially infective, it is not usually considered practical or necessary to treat all such wastes as infective.*

Spill management. The management of spills in the laboratory usually consists of flooding the contaminated area with liquid disinfectant, being careful not to generate aerosols, allowing adequate contact time with disinfectant, cleaning up the spill, reapplying fresh disinfectant, and final cleanup. Protective clothing is always worn. When spills involve large volumes of infectious agents, personnel should leave the area until aerosols have settled before cleanup is begun. Variations of this procedure are used for hospital spills, where emphasis is placed on first absorbing and cleaning the spill and then disinfecting the area. The reason for the difference is the concentration of the microorganisms present in the spill and the likelihood that the general public may be exposed and inadvertently spread contamination elsewhere.

SUMMARY

Containment of microorganisms in laboratories (or other workplaces) is critical to the health of workers and to the community. Engineering controls such as safety equipment and facility design are important because, except for monitoring and appropriate maintenance, they do not require worker input to be effective. Despite this, experience indicates that the use of worker-initiated workplace controls in the form of good work practices and carefully executed techniques is critically important in minimizing biohazardous exposures in the workplace.

Biosafety Program Management

The primary focus of an institutional biosafety program is to ensure that workers, their colleagues, and the community (which includes the general population and the environment) are not adversely affected by potentially hazardous microorganisms or their toxins. Biosafety program components usually include program support, a biosafety officer or specialist, an institutional biosafety committee (IBC), a biosafety manual of written policies and procedures, an occupational health program for relevant employees, and employee training or information communication. Biosafety programs vary markedly depending on the size of the institution and its activities (such as education, industrial research and development, manufacturing, medical patient care, or food service).

PROGRAM SUPPORT

Without strong program support, even the best biosafety program has little chance of succeeding. It is critical to have administrative and financial support. Without support from upper management it is impossible to implement committee decisions and biosafety policies. Inadequate financial support of biosafety activities is equally problematic. Program financing usually comes from one of two general sources: fee for service or institutional overhead. Each method of support has its pros and cons, but it is important to prevent a situation where health and safety services are not accessed because of their cost.

BIOSAFETY SPECIALIST

As institutional activities vary, so do the responsibilities and duties of the biosafety officer/specialist. A strong background in microbiology is imperative so that this person may interact successfully with the scientific and technical community. In addition to microbiology, knowledge in the disciplines of molecular biology, infectious diseases, public health, sanitation, environmental microbiology, and epidemiology is extremely useful. Besides these academic credentials, it is important for a biosafety professional to have worked with microorganisms. An understanding of workplace procedures and equipment becomes invaluable when performing a risk assessment on a work activity or designing workable containment for experiments. Without such experience and an

appropriate academic background, a health and safety professional will find it difficult to interact with scientific and technical staff and provide the biosafety assistance they need.

Because it is often necessary to receive input not only from the scientific staff but also from the biosafety committee and the administration, the biosafety professional must be able to lead diverse groups to a consensus. Biosafety officers work with architects, contractors, facility engineers, medical staff, animal facility personnel, and maintenance and custodial services, to mention only a few groups.

INSTITUTIONAL BIOSAFETY COMMITTEE (IBC)

The original impetus to form these committees is found in the first publication (1976) of the "NIH guidelines for research involving recombinant DNA molecules." NIH mandated that institutions receiving NIH funding conduct recombinant DNA research in compliance with their guidelines. Formation of an IBC was required. Committees were charged to review research activities involving recombinant technology for compliance with the guidelines and to oversee the safe conduct of work. Initially, many institutions chose to have their committees oversee only work activities involving the use of recombinant technology; consequently, work with infectious agents was not scrutinized. Today, most biosafety committees set policy and procedures for all activities involving infectious agents, materials, and animals, in addition to experiments using recombinant technology.

As defined by the NIH, IBCs overseeing recombinant activity must have no fewer than five members selected for their experience and expertise in the technology and their capability to assess the safety of the work and any potential risk to public health and the environment. At least two members must be chosen from outside the institution to represent the interests of the community. As committee responsibilities broaden, in addition to a strong core of microbiologists and molecular biologists, experts in other disciplines (such as animal resources, plant pathology, and gene therapy) are needed.

IBCs must interact with other review bodies within the institution. The use of infectious animals alters the safety considerations to be addressed and the questions that must be answered, so institutional animal care and use committees (IACUCs) also become involved. When research activities involve the development of treatments for human diseases or the use of other hazard materials, IBCs will need to interact with human subject review boards (IRBs), radiation safety committees (RSCs) and radiation safety officers, chemical safety committees (CSCs) and chemical hygiene officers, in order to approve research proposals. In the interest of facilitating the timely review of work, it is imperative that the committees work together effectively.

BIOSAFETY MANUAL

One of the more challenging tasks of a health and safety professional is getting information about health and safety policy, regulations, and safety practices into the workplace. A biosafety manual is one means of handling the communication of information and policy.

At the CDC Third National Symposium on Biosafety in 1994, a workshop was held covering the topic of biosafety manuals and their use and maintenance. Most of the health and safety professionals attending the workshop agreed that it is useful to have some type of biosafety manual. Many participants indicated that their institution had manuals and that these manuals were not used for a variety of reasons. Reasons for this included the fact that the manuals were difficult to use or out of date; employees did not know of their existence; or policies outlined in the manual did not have administrative and supervisory support. To help avoid some of these problems, including spending a great deal of time writing a manual that is destined to be underused, some preparation and planning is helpful. The following series of questions will help define the type of document appropriate for an institution:

- ➢ Why have a manual?
- ➢ What is the manual supposed to accomplish? (What should its scope be?)
- ➢ What support is needed for acceptance?
- ➢ Who should write it?
- ➢ What should be included?
- ➢ Should the manual be printed or available electronically?
- ➢ How should the manual be distributed to users?
- ➢ How can the document be kept current?

No single type of biosafety document is suitable for all work settings; at least five manual formats were identified at the CDC workshop. They included a formal, lengthy, administrative manual that covers all safety topics; a user manual or handbook that has safety information specific to a worksite such as a laboratory; a complete reference document on one subject, such as a bloodborne pathogen exposure control plan; a worksite procedure-specific manual for a defined group of people (waste handlers, glass washers); and a booklet or binder of work practices with all SOPs. Manuals need to be updated frequently and now are usually included on the institution's computer network.

OCCUPATIONAL HEALTH PROGRAM

When setting up an occupational health program for workers potentially exposed to infectious agents or other hazardous materials, decisions must be made regarding the focus of the program and whether it will include acute exposure-related problems and/or disease prevention and wellness programs. The purpose of an occupational health program is fourfold:

- ➢ To provide a mechanism to detect job-related illnesses
- ➢ To determine the adequacy of protective equipment and procedures and verify that hazardous agents are not being released into the general environment
- ➢ To establish baseline pre-exposure status
- ➢ To assess the presence of preexisting conditions that would put an employee at increased risk

Health surveillance programs vary greatly, depending on the microorganisms being handled, the nature of the technical activities being conducted, the volume or concentration of material, and available medical facilities. Exposures to toxic chemicals, radionuclides, physiologically reactive biological and pharmaceutical products, animal allergens, and physical stresses also require consideration.

Some possible components of an occupational health surveillance program include taking medical and occupational histories, conducting physical examinations, laboratory testing, immunization, and serum storage, where indicated. If possible, it is advantageous to include the services of specialists in the fields of occupational health medicine and infectious diseases.

Work with infectious agents requires the evaluation of specific immunizations. Although there is no question that persons working with human blood and related products should receive hepatitis B immunization, there may be reasons to waive immunization with some less effective vaccines. An infectious disease physician should be consulted on such matters. Recommendations for the use of vaccines are included in the agent summary statements in Section VII of the CDC/NIH biosafety document (CDC/NIH, 1999) and a comprehensive listing of immunoprophylaxis for personnel at risk is found in the NRC resource, *Biosafety in the Laboratory* (NRC, 1989, pp 60–62). See also Recommendations of the Advisory Committee on Immunization Practices: adult immunizations (CDC, 1991a), use of vaccines and immune globulins in persons with altered immunocompetence (CDC, 1993b), and immunization of health-care workers (CDC, 1997a).

Serum banking, another component of a medical surveillance program, has less support now than in the past. Although such a resource can provide invaluable information regarding work-related exposures, this benefit must be weighed against such basic considerations as whether adequate facilities and technical support for long-term storage exist. Decisions regarding serum storage and testing should be based on agents handled, availability of reliable tests, likelihood that infection will produce a serological change in exposed persons, and the ability to maintain a secure storage facility. Results of employee medical evaluations must remain confidential, with information being released only with the employee's consent.

Considerations involving host susceptibility must be taken into account, and some of these have been mentioned earlier in the risk assessment section. When decisions regarding employee health issues are made, the decision-making process should include the employee, the physician, and the employer. For additional information on medical surveillance programs for research and biotechnology settings, refer to Goldman (1991, 1995).

INFORMATION AND EDUCATION

All persons whose work involves the handling of infectious organisms or materials must receive adequate information and education to enable them to work safely. Biosafety programs should include a mechanism to provide safety information to employees at all stages of their employment (new, altered work tasks and long-term) as well as periodic safety updates.

In instances where regulations mandate training, such as the OSHA bloodborne pathogen standard, training content may be specified and written control plans required. Many regulations address frequency of training, record-keeping requirements, and qualifications of trainers.

Training materials developed for work with infectious materials must include a description of the biology of the agent(s), including symptoms of the disease; a review of the operations and procedures, with emphasis on potential sources of exposures and means of control; the correct use of containment equipment when applicable; review of acceptable work practices; decontamination methods and waste disposal; and emergency procedures. Equally importantly, personnel need to be made aware of the human factors (such as fatigue, inattentiveness, and haste) that predispose workers to accidents. Employees should understand that although employers must provide appropriate facilities and equipment to conduct work safely, they are responsible for following safety practices and procedures in order to protect themselves, their colleagues, and the community.

One challenge of health and safety training is to provide appropriate and factual information that is geared to the language and educational level of the employees. Clearly information is more readily received when it is presented in an interesting or creative format. Although trainers now have access to an excellent collection of tools such as professionally produced videotapes and interactive computer educational programs, it is critical that training not be a solitary event.

Computers are now making new sources of health and safety information available to the health and safety community. In 1994 the Massachusetts Institute of Technology biosafety group, in conjunction with the American Biological Safety Association (ABSA), initiated an electronic biosafety discussion list (BIOSAFTY). Other useful lists include:

- ➢ University of Vermont's list on environmental health and safety
- ➢ Association for Professionals in Infection Control and Epidemiology (APIC)
- ➢ Duke University's Occupational and Environmental Medicine Web Resources

IDEAL BIOSAFETY PROGRAMS

The ideal biosafety program has strong administrative support from upper management and is funded adequately so that worker safety is not compromised. Depending on the volume of microbiological activity and the hazard associated with the microorganisms handled, a biosafety specialist should become involved in health and safety

considerations. In some cases, it is not feasible to have a dedicated biosafety staff person, because the volume of work is low and the organisms handled are of minimal or low risk. Under these conditions it may be advisable to seek the assistance of a consultant who can work with the existing health and safety staff. When clinical activities are involved, infection control practitioners are an excellent resource for safety departments. In hospital settings, infection control practitioners may oversee clinical laboratory biosafety matters using policies approved by an infection control committee.

To effectively implement institutional biosafety committee (IBC) policies and decisions, institutional administrative support at the highest level must exist. Committee members must be knowledgeable, make informed and realistic decisions, and have credibility among their peers so that committee decisions will be accepted and implemented. Committee business and, ultimately, research activity are facilitated by timely attention to pertinent matters and, where needed, interaction with other institutional bodies such as animal resources, IACUCs, RSCs, CSCs, and IRBs.

No one biosafety manual or training program is appropriate for all work settings. Rather, institutions must strive to prepare material and training that provide their employees with pertinent material in a format that will be understood and utilized. It is the challenge of every safety professional to develop these educational components so that they are not only relevant but interesting.

For the occupational health program to be effective and used, providers must offer services as required by law, be familiar with workplace activities, be responsive to the needs of employees, and interact with the IBC and biosafety specialist. Employees who are indifferent to occupational health programs such as immunization and serum storage are more likely to use them if, where possible and practical, services are performed at the worksite.

ASSESSING COMPLIANCE

Although there is often urgency to develop and implement health and safety programs and controls, the need to assess their efficacy following implementation is sometimes overlooked. Such a review is imperative in order to be assured that the safety practices have been incorporated into work activities and that they are minimizing potential hazards.

Use of Audits to Identify Problem Areas

Self-audits of required safety practices provide a measure of compliance achievement. In work environments where hazardous aerosols are generated, such as agricultural processing facilities, one would begin by monitoring for compliance with personal protective equipment and clothing requirements. In laboratory settings the criteria for the designated biosafety level(s) can be used for the critical elements of the audit.

Routine operating procedures should include a safety check, for example, to determine that equipment (such as a biosafety cabinet or hematocrit centrifuge) is functioning properly or that work surface disinfectants and spill kits are on hand. When agents requiring higher containment are handled, ventilation system function must be checked and actual work practices and techniques reviewed to ensure containment.

Regular safety audits should be carried out quarterly or semiannually by designated safety specialists accompanied by the laboratory supervisor. Deficiencies can be pointed out and abated during the inspection. A written report, suggesting corrective actions, can be sent to the laboratory supervisor, who should report progress on remediation within a designated period of time. Notification of biohazards in use and a list of associated personnel should be obtained from the laboratory supervisor. The inspection program can be used to review information on the facility, work, and workers and serve as a reminder to update the biohazard database.

Annual Biosafety Review

An annual renewal of biohazard registration also helps to remind each responsible supervisor to review the work in progress and keep the information updated. Pathogen or biohazard registration programs used by many institutions provide supervisors with a form to expedite such an update.

Incident/Accident Statistics

Although small statistical changes in incident/accident figures do not usually indicate real deficiencies in a biosafety program, some institutions only judge the status of their safety program by a statistical review of changes in OSHA-recordable incidents.

The positive changes brought about through education and training in preventive methods can be measured with specific outcome audits. For example, in determining the effect of training and safety equipment on the number of needlestick incidents, trends in reports on such injuries show the cost-benefit of the changes. Observations of increases in such injuries, or the reporting of sentinel events (events whose single occurrence is of sufficient concern to trigger systematic response) highlight the need for intervention efforts. Such events can be used as tools for continuous quality improvement if action limits (the criteria for intervention) are defined (Birnbaum, 1993).

Work practices must be assessed for efficacy so that protective practices can be reinforced and unsafe practices altered.

CURRENT TOPICS IN BIOSAFETY

Bloodborne Pathogens

Hepatitis B virus has been the most significant occupational infector of health care and laboratory personnel during the past 50 years. This fact, coupled with the identification of

the human immunodeficiency virus (HIV), the causative agent of acquired immune deficiency syndrome (AIDS), prompted the development and implementation of measures that would promote worker protection. OSHA pioneered the regulation of work environments associated with potentially infectious microorganisms with its publication of a standard regulating occupational exposure to bloodborne pathogens (OSHA, 1991). In addition to the standard, OSHA continues to publish new compliance assistance instructions for their enforcement officers that provide useful information for those covered by the regulation (OSHA, 1999).

The standard applies not only to the health care community but to all occupations (such as emergency responders, law enforcement officers, and morticians) in which there is a potential for exposure to human blood. Bloodborne pathogens are defined as microorganisms that may be present in human blood and body fluids and are capable of causing disease in human beings. While HIV and hepatitis B and hepatitis C viruses are the bloodborne pathogens most frequently associated with occupational infections, other bloodborne microorganisms associated with diseases, such as syphilis and malaria, have also been responsible for work-related infections.

HEPATITIS B VIRUS (HBV)

Epidemiology. Hepatitis B virus infects at a minimum 136,000 persons in the general U.S. population annually, with an estimated 1,012 of these infections attributed to high-risk health care workers, i.e., those having frequent occupational contact with blood (Shapiro, 1995). Among these 1,012 infected health care workers there will be an estimated 250 cases of clinical hepatitis, 50 HBV carriers, 13 cases of chronic hepatitis, and 22 deaths. Prior to licensure of the hepatitis B vaccine in 1981, an estimated 17,000 health care workers were infected annually with HBV. The estimated incidence of HBV among health care workers in 1983 was threefold higher (386/100,000) than the incidence in the general population (122/100,000) (Mahoney et al, 1997). By 1995 the incidence of HBV infections among health care workers decreased by more than 95 percent (9.1/100,000) and was fivefold lower than the incidence of HBV infection in the general population (50/100,000), which had decreased by 60 percent. The periods of greatest decline in infections occurred between 1986–1987, when the recombinant DNA vaccines were licensed, and from 1992–1993 when the OSHA bloodborne pathogen standard was implemented.

Disease. Hepatitis B virus, a DNA virus and member of the *Hepadnaviridiae* family, infects liver cells and has the potential to cause serious liver disease. The incubation period (the time between exposure to the virus and onset of illness) ranges from two to six months, and at least 50 percent of the cases of acute infection are asymptomatic. For the remainder, disease varies from mild to severe or even fatal. Symptoms of clinical illness may include loss of appetite, rash, fever, abdominal discomfort, nausea and vomiting, jaundice, extreme fatigue, anorexia, fever, and joint pain. The majority of infections in adults are self-limited with symptoms lasting several weeks. Most infected persons clear their virus and have lifelong immunity to re-infection; however, 5 to 10 percent of persons with acute HBV infection develop chronic infection and generally remain infected for their lifetime. Some with chronic infection may be asymptomatic carriers, while others develop liver inflammation, cirrhosis, or hepatocellular carcinoma. Persons with chronic HBV infection have an estimated 20 percent lifetime risk of dying of cirrhosis and a 6 percent risk of dying of hepatocellular carcinoma (Beasley & Hwang, 1984; McMahon et al, 1985). A safe effective recombinant vaccine is available and immunization of high risk health care workers is strongly recommended (CDC, 1997a). This same publication also makes recommendations for postexposure prophylaxis for percutaneous and permucosal exposure to HBV.

Transmission. In occupational settings, hepatitis B virus is transmitted by parenteral inoculation and mucous membrane and nonintact skin exposure to human blood, blood products, bloody body fluids, semen, vaginal secretions, and saliva. Airborne transmission has been postulated. But true airborne transmission of HBV probably does not occur, rather transmission occurs due to direct contact with droplet-contaminated surfaces (Favero, 1985). Sexual and perinatal transmission occurs in the general population. Persons exposed to HBV-contaminated needlesticks have a 6 to 30 percent risk of HBV infection (OSHA, 1991, preamble).

HEPATITIS C VIRUS (HCV)

Epidemiology. Hepatitis C virus, an RNA virus in the *Flaviviridae* family, is the primary etiologic agent of parenterally transmitted non-A, non-B hepatitis. HCV is the most common chronic bloodborne infection in the United States. There are an estimated 3.9 million infected persons nationwide with 8,000–10,000 associated deaths each year. The prevalence of HCV among health care workers, including orthopedic, general, and oral surgeons, is no greater than the general population (1–2 %) and is 10-times lower than that of HBV infection (CDC, 1998c).

Disease. Persons with acute HCV infection have either asymptomatic or mild clinical disease: 60–70 percent have no apparent symptoms, 20–30 percent may have jaundice, and 10–20 percent may have nonspecific symptoms such as anorexia, malaise, or abdominal pain (CDC, 1998b). The average incubation period is six to seven weeks.

Following acute infection 15 to 25 percent of persons appear to resolve their infection. However, chronic HCV infection with persistent viremia develops in most persons (75–85%). The course of chronic liver disease is usually insidious, progressing slowly without symptoms or physical

signs in the majority of patients during the first two or more decades after infection. Frequently this status goes unrecognized until the person is identified as HCV-positive during blood-donor screening. Studies indicate that cirrhosis develops in 10 to 20 percent of persons with chronic disease older than 20–30 years, and hepatocellular carcinoma in 1–5 percent (Seeff et al, 1992; Fattovich et al, 1997). An HCV vaccine is currently not available and antiviral therapy is recommended for patients with chronic HCV who are at greatest risk for progression to cirrhosis (NIH, 1997).

Transmission. HCV is transmitted primarily through large and repeated direct percutaneous exposure to blood. Work-related infections have resulted from HCV-contaminated needlesticks or cuts with sharp objects and blood splashed to mucous membranes. The average incidence of anti-HCV seroconversion following needlesticks or sharps exposures from an HCV-positive source is 1.8 percent (range 0–7%) (CDC, 1998c). Risk factors associated with transmission include blood transfusion, injection-drug use, employment in patient care or clinical laboratory work, exposure to a sex partner or household member who has a history of hepatitis, exposure to multiple sex partners, and low socioeconomic level. With the advent of blood screening technologies, transfusion-related infections are now rare (Schreiber et al, 1997). Injection-drug use currently accounts for most of the HCV transmission in the United States (Alter, 1997).

HUMAN IMMUNODEFICIENCY VIRUS (HIV)

Epidemiology. Through Dec. 31, 1998, the CDC had received reports of 188 cases of documented or "possible" occupationally acquired HIV infection among health care workers. A documented means of occupational exposure has been identified in 54 of the cases and 25 of these individuals have developed AIDS (acquired immunodeficiency syndrome). The remaining 134 workers were classified as "possible" occupational HIV exposures because neither the date of infection nor its source could be documented. Forty-six of the documented cases resulted from percutaneous exposures, five from mucocutaneous (mucous membrane and/or skin injury) exposures, two from dual percutaneous and mucocutaneous exposure, and one from an unknown source. Forty-nine of the 54 documented seroconversions resulted from exposure to blood from HIV patients, three to concentrated virus, one to visibly bloody fluid, and one to an unspecified fluid. By occupation, 19 laboratory workers and 22 nurses sustained the greatest number of documented seroconversions (CDC faxline––*AIDS Information Document* #260230).

Disease. HIV is an RNA virus in the family *Retroviridae*, subfamily *Lentivirinea*. Lentiviruses encompass agents able to cause chronic infections with slowly progressive neurological impairment. Persons infected with HIV may remain healthy for years before the virus, which infects the cells of the immune system, ultimately destroys that system. AIDS represents the later clinical stage of HIV infection. Following infection with HIV, persons may be asymptomatic or within several weeks to several months develop an acute self-limited flu-like illness that lasts for one to two weeks. Because symptoms disappear and individuals often remain healthy for a number of years, many infected individuals are unaware of their HIV status. Presently there is no vaccine to prevent infection with HIV nor is there a "cure" for AIDS. A number of anti-retroviral therapies are currently available to help keep HIV replication under control. Guidelines for treatment of exposed health care personnel have been published by the CDC (1998a).

Transmission. HIV is transmitted through exposure to human blood and certain body fluids. In the work setting, infection can result from parenteral, nonintact skin, or mucous membrane (eyes, nose, and mouth) exposure to contaminated materials. Data from needlestick studies indicate that persons exposed to HIV-contaminated needles have a 0.3-percent chance of seroconversion to HIV and a 0.09-percent seroconversion rate as the result of mucous membrane exposures (Short & Bell, 1993).

Epidemiological data on the consequence of parenteral exposure to HIV, HBV, and HCV indicate that one of the most critical workplace controls is the reduction of sharps-related incidents.

OSHA STANDARD

The intent of the OSHA Bloodborne Pathogens Standard is to prevent or minimize parenteral, nonintact skin, and mucous membrane exposure to human blood and body fluids in the workplace. To achieve this goal the standard requires employers whose employees are potentially exposed as the result of their work activities to implement an administrative mechanism for compliance and a series of workplace controls to prevent or minimize exposure (OSHA, 1991). Employers must develop an exposure determination plan (a systematic means of determining which of their employees is at risk from occupational exposure to bloodborne pathogens) and an exposure control plan that outlines how their institution will meet the standard requirements. Compliance methods specific to an institution or facility are included in the exposure control plan.

CONTROLS

The infection control concept of universal precaution—that all human blood and certain human body fluids are to be treated as if known to be infectious for HIV, HBV, HCV, and other bloodborne pathogens—is a key component in prevention of work-related exposure. The OSHA standard outlines potentially infectious materials (including HIV-, HBV-, and HCV-infected cells, tissues, and animals) and specifies control measures that will prevent or minimize work-related infections.

The standard mandates engineering controls (needle-disposal containers and equipment for reducing aerosols and splatter); work practice controls with special emphasis on personal protective clothing and equipment (such as gloves and face and eye protection) and hand-washing; sharps management procedures (needle-handling procedures such as not resheathing needles by hand and the use of rigid sharps-disposal containers); culture and specimen labeling and transport requirements; housekeeping (including disinfection, disposal of infectious waste, and spill management); handling of contaminated laundry; communication of hazard to employees (training); and general workplace practices and procedures. Biosafety level 2 (BSL-2) practices are required for laboratory activities involving clinical materials. Work may be performed on the open bench as long as procedures do not generate significant aerosols. Aerosol-generating procedures must be performed in a BSC or otherwise contained. The CDC/NIH publication *Biosafety in the Microbiological and Biomedical Laboratory* provides guidance (agent summary statements) for handling hepatitis viruses and HIV (retroviruses) (CDC-NIH, 1999). Additional information regarding practical disinfectants for HIV and HBV is available in Rutala (1996).

Immunization is a critical component of the bloodborne pathogen hazard control. There is currently no means of immunizing people against HIV or HCV, but an effective vaccine for HBV is available. Employers must offer hepatitis B vaccination to employees whose work activities bring them into contact with bloodborne pathogens, as well as document their refusal to be immunized. Some latitude on up-front HBV immunization is given to employers whose employees render first aid only as a collateral duty, not as part of their job description (Clark, 1992). Employers must also provide for the immediate and follow-up medical and counseling needs of employees who sustain an occupational exposure.

Because there is widespread agreement among the medical community and other regulated workplaces that indeed workers are at risk from bloodborne pathogens, significant progress has been made toward reducing the hazard of bloodborne pathogens in the workplace.

Tuberculosis

Tuberculosis (TB) is a bacterial disease, caused by *Mycobacterium tuberculosis* complex (*M. tb*), that is responsible for morbidity and mortality worldwide. This complex consists of *M. tuberculosis* and *M. africanum*, for which man is the primary source of infection, and *M. bovis,* primarily from cattle; it occurs only rarely in primates, badgers, and other animals (Chin, 2000).

EPIDEMIOLOGY

Tuberculosis, common outside the United States, is estimated to affect one-third of the world's population (CDC, 1993c). There are 8 million new cases of tuberculosis each year. If prevention and control methods are not improved, during this decade approximately 90 million new cases of tuberculosis can be expected worldwide. Transmission of most infections occurs prior to the initiation of anti-tuberculosis therapy (Lundberg, 2000). The emergence of drug-resistant TB is also being reported worldwide and is a serious problem in the United States (Stratton, 1993). In the United States, only 10 percent of *M. tb* strains were resistant to one or more drugs in the years prior to 1984. Since 1988, there have been numerous outbreaks caused by multiple drug-resistant strains (MDR-TB). The mortality rate is approximately the same (40 to 60%) in those with MDR-TB, despite treatment, as in TB cases that go untreated (CDC, 1991b).

The number of tuberculosis cases had declined by 74 percent between 1953 and 1984, but decline slowed in 1985, and new cases of TB in the United States began to increase significantly. There was an increase in the cases reported in every racial or ethnic group except non-Hispanic whites and American Indians/Alaskan natives from 1985 to 1992. The CDC has estimated that there are between 10 and 15 million asymptomatic, infected people in the United States. These facts indicate that the routine processing of sputum in high-risk urban areas is a potential source of laboratory-acquired infection.

Risk assessment and epidemiological studies (CDC, 1994b) show that the prevalence of TB is not distributed evenly throughout a population. Some groups are at higher risk of TB because of increased risk of exposure; others have a higher risk of progressing to active TB following infection. Those with increased risk of exposure include the foreign-born from areas with high prevalence of TB (Asia, Africa, the Caribbean, and Latin America); the medically underserved, such as African Americans, Hispanics, Asians and Pacific Islanders, American Indians and Alaskan Natives; homeless persons; current or former correctional-facility inmates; alcoholics; intravenous drug users; and the elderly. Those who are at higher risk of progressing to active TB from latent infection include those recently infected (within the previous two years); young children (less than 4 years old); persons with fibrotic lesions that show up on chest radiographs; and persons with certain underlying medical conditions such as HIV infection, silicosis, gastrectomy or jejunoileal bypass, being 10 percent below ideal body weight, chronic renal failure with renal dialysis, diabetes mellitus, immunosuppression from receipt of high-dose corticosteroid or other immunosuppressive therapy, and some malignancies.

Much of the current increase in cases of tuberculosis has been attributed to HIV-infected people, particularly in Africa and Southeast Asia. Among persons co-infected with HIV and *M. tuberculosis*, the risk for developing active TB is increased because of the concurrent immunosuppression induced by HIV. The annual risk of progression into active TB among individuals infected with both HIV and TB is 5 to 15 percent, depending on the degree of immunosuppression (Raviglione

et al, 1995). The CDC Advisory Committee on the Elimination of Tuberculosis (1989) recommended that HIV-infected individuals be screened for active TB as well as latent TB and be offered appropriate curative or preventive therapy (CDC, 1993a). Current studies indicate that HIV-positive TB carriers are no more likely than their HIV-negative counterparts to spread TB to close contacts (Espinal et al, 2000).

TRANSMISSION

Tuberculosis is usually transmitted by the inhalation of infectious droplet nuclei suspended in the air, from coughing, sneezing, singing, or talking, by an individual who has a pulmonary or laryngeal TB infection. Prolonged close contact with an infectious person may expose individuals such as family members or coworkers and lead to their infection. Although direct exposure to mucous membranes or invasion through breaks in the skin can result in infection, it is extremely rare. With the exception of laryngeal infections, extrapulmonary TB infection, even with a draining sinus, is usually not communicable. Bovine tuberculosis, caused by *M. bovis*, results from drinking unpasteurized milk or dairy products from infected cattle, although there have also been cases in which farmers or animal handlers have been exposed to infectious aerosols (Chin, 2000).

DISEASE SYMPTOMS AND PROGRESS

Symptoms of tuberculosis include fatigue, fever, and weight loss early in the disease. Hoarseness, cough, and hemoptysis (blood-tinged sputum) appear later as the disease is localized in the respiratory tract.

It can take from one to four months from the time of infection to a demonstrable pulmonary lesion or a positive tuberculin reaction. Thus it is understandable that the transmission of most infections occurs prior to the initiation of anti-tuberculosis therapy. (Lundberg, 2000)

The initial infection with the tubercle bacillus is usually asymptomatic, but in a few weeks sensitivity to tuberculin (a purified protein derivative of *M. tuberculosis* used for skin testing) usually develops, as manifested in a positive skin test. Progression to active disease is most likely in the first two years after infection, but can occur any time throughout life. Those who are actively shedding viable tubercle bacilli in sputum, including those who are inadequately treated, are a risk to others, but children with primary TB do not usually infect others. When effective treatment is given, communicability can be eliminated in several days or a few weeks, when tubercle bacilli are no longer visible in an acid-fast smear of patient sputum.

The internal lesions that develop in the respiratory tract usually heal with minor or no change, except for occasional calcifications in pulmonary or tracheobronchial lymph nodes. There is a lifelong risk of reactivation in 95 percent of those infected who enter this latent stage. In about five percent of those infected, the initial infection progresses to pulmonary TB or bacteremia with dissemination to other organs. Infants, adolescents, and young adults have a more serious outcome from the initial infection in tuberculosis. Tuberculosis is not very infectious in terms of unit of time exposed to the bacillus; that is, brief exposure rarely results in infection. However, long terms of exposure to chronic, asymptomatic cases, as with household contacts, lead to an overall 30-percent risk of infection and a one- to five-percent risk of active disease within a year. Reinfection or reactivation of the latent disease leads to progressive pulmonary tuberculosis, which can lead to death within two years if untreated (Chin, 2000). The lifetime risk of developing active disease for those infected as infants is estimated at 10 percent.

RISK OF OCCUPATIONAL EXPOSURE

The key element in protecting workers from the risk of occupational exposure is risk assessment. The current CDC guidelines for protection of workers from tuberculosis (CDC, 1994b) address the health care industry. Risk assessment procedures can identify settings (bronchoscopy performed on suspected TB patients, autopsies on deceased patients who had active TB) in which a higher level of protection is needed, and if so, the situation should be documented and the protection implemented. The Occupational Safety and Health Administration is promulgating a standard based upon these guidelines, but it has not yet been issued. A risk assessment can be done at any worksite, after which the appropriate administrative and engineering controls and personal respiratory protection can be implemented.

In the workplace, health care workers, including nursing home and emergency personnel, who provide patient care are at risk of aerosol-borne infectious droplet nuclei from patients. Those who work in clinical, research, or production facilities with *M. tuberculosis*, *M. africanum,* or *M. bovis* are at risk from contact and percutaneous routes as well as from inhalation of droplet nuclei in aerosols produced during common work procedures (Chin, 2000). Others who provide service to high-risk individuals such as those in shelters and prisons are also at increased risk.

CDC published a report on the risk for occupational exposure to TB (CDC, 1995). Although there are certain recognized limitations to this study, it is encouraging to find published data on the relationship between occupational exposure and illness. Of the 2,206 deaths from TB from 1979 to 1990, 1,024 (46.4 percent) were in workers in 21 groups that met the criteria for occupational risk. These groups were further categorized into four risk groups: high potential for exposure to TB, potential for exposure to silica, low socioeconomic status (SES), occupation without other recognized risk factors, and unknown risk factors. It should be noted that the high-risk groups include funeral directors and health care service workers, such as nursing aides, orderlies, and attendants. A list of the occupations in the four risk groups and the proportionate TB mortality rates is included in the CDC (1995) reference.

EMPLOYEE PROTECTION FROM EXPOSURE

The 4th edition of *Biosafety in Microbiological and Biomedical Laboratories* (*BMBL*) (CDC/NIH, 1999) provides few instructions on the use of respirators with microbial pathogens. Guidance for respirator selection is not included. Respirators are just one of the primary barriers to be considered when working outside of a biological safety cabinet at biosafety level-3 (BSL-3). Respiratory protection is specifically recommended when the worker is in a room containing an infected animal. Even at vertebrate animal biosafety level 2 (ABSL-2), respirators should be considered whenever procedures with a high potential for creating aerosols are done, i.e., vigorous shaking or mixing, necropsy, intranasal inoculation, and harvesting infected tissues. When working at ABSL-3, respiratory protection is to be worn by all personnel entering animal rooms and for all work that is not done within a BSC or other primary barrier. Personnel working at BSL-4 or ABSL-4 may use a one-piece positive pressure suit, ventilated by a life support system with HEPA filtration (CDC/NIH, 1999). Those using these suits should be in a respiratory protection program. The Center for Infectious Disease, Infection Control Branch of the CDC issued *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health Care Facilities* (CDC, 1994b). The CDC recommended the use of respirators by health care workers when entering the room of a patient in isolation for TB or suspected TB, when present during cough-inducing or aerosol-generating procedures on such patients, and in other settings where administrative and engineering controls cannot be ensured. These would include emergency transport, urgent surgical care, or urgent dental care of such patients. These guidelines outline minimum criteria for acceptable respiratory protection. According to the CDC Guidelines (CDC, 1994b), facilities that do not have isolation rooms and do not perform cough-inducing procedures on patients who might have TB may not need to have a respiratory protection program for TB. Such facilities should have written protocols for the early identification of patients with signs and symptoms of TB and procedures for referring such patients to a facility for proper evaluation and management.

Enforcement of OSHA regulations. In February 1996, OSHA published enforcement procedures for occupational exposure to tuberculosis (OSHA, 1996). This document indicated that inspections would be conducted in response to employee complaints, fatalities, and catastrophes; or in workplaces where the incidence of tuberculosis infection is greater than in the general public, such as health care facilities, correctional institutions, long-term care facilities for the elderly, homeless shelters, and drug treatment centers. A written program must be implemented for respiratory protection and meet the performance criteria for respiratory protection outlined in the 1994 CDC guidelines as well as those for compliance with OSHA 1910.139.

Respiratory protection equipment standards. In 1997, OSHA published a proposed rule on occupational exposure to tuberculosis (OSHA, 1997). This proposal cannot be enforced by OSHA until the ruling is published in its final form. Those with occupational exposures to tuberculosis should rely on CDC's 1994 guidelines and OSHA 1910.139 for guidance on proper use of respiratory protection against *M. tuberculosis*, and review current literature for publication of the final ruling or other relevant documents from OSHA, NIOSH, and the CDC.

According to the CDC (1994d), the standards to be met by respiratory protective equipment used in health care settings to protect against TB include the following:

- ➢ The ability to filter particles as small as 1 μm in size in the unloaded state with a filter of 95 percent (filter leak of less than 5 percent), given flow rates of up to 50 L/min.
- ➢ The ability to quantitatively or qualitatively test fit in a reliable way to obtain a face-seal leakage of no more than 10 percent.
- ➢ The ability to fit different facial sizes and characteristics of health care workers; that is, to be available in at least three sizes.
- ➢ The ability to be checked for facepiece fit, according to OSHA and good industrial hygiene practices, by the health care worker each time the respirator is put on.

Although certain regional OSHA requirements may still include mandatory positive-pressure air-purifying particulate respirator (PAPR) or full-face, HEPA-filtered respirators, the most recent recommendations from the CDC (1994c) outline the performance-based criteria listed above for the selection of respiratory protection (see CDC, 1994b, supplement 4). These recommendations are based upon the premise that aerosolized microorganisms are particles that can be removed by a filter—i.e, a particulate filter will remove the organism with at least the efficiency it is certified for (95 percent for a N95 filter) (Brosseau et al, 1997; Qian et al, 1998).

All particulate respirators approved under 42 *CFR* Part 84 NIOSH certification procedures and all atmosphere-supplying respirators meet the OSHA criteria (NIOSH, 1996). However, if the procedures require sterility, respirators with exhalation valves and respirators which may be under positive pressure cannot be used. Circumstances in which the risk may justify a level of respiratory protection exceeding the minimum criteria include, but are not limited to, bronchoscopy performed on patients with suspected or known tuberculosis and autopsy performed on persons who were suspected of or known to have tuberculosis (CDC, 1994b).

WORKPLACE CONTAINMENT

Specific recommendations for protection from tuberculosis are made in regulatory as well as advisory documents; it is recommended that the current literature be reviewed regularly for revised standards and guidelines.

Patient care. Infection control guidelines for the care of patients with tuberculosis have been provided and updated periodically since the mid-1970s by the CDC's Hospital Infections Branch (Garner & Simmons, 1983). Concern for employee health in the hospital environment was the subject of a separate set of CDC guidelines (Garner & Favero, 1986). The CDC has published draft guidelines for preventing the transmission of TB in health care facilities, extending them to include protection of both patients and personnel (CDC, 1993a; CDC, 1994b). The CDC made it clear that the purpose of the guidelines was to make recommendations to reduce the risk of transmitting TB to health care workers, patients, volunteers, visitors, and other persons in health care settings. The recommendations were written to apply to inpatient facilities where health care is provided, such as hospitals, prison medical wards, nursing homes, and hospices.

In patient care settings, it is important to control TB at the source by identifying TB patients or those at high risk and taking the time to train such patients to control the formation and release of infectious droplets, for example, by using tissues to cover sneezes and coughs.

The CDC guidelines were adopted by OSHA in an advance notice of proposed rulemaking as requirements to protect employees from exposure and disease (Decker, 1993). Requirements include a written TB infection control plan, assignment of responsibility for the program, exposure determinations, evaluation of risk to employees, development of a written exposure control plan based on the risk assessment, and periodic reassessment of risk to evaluate the effectiveness of the TB infection control program (Clark, 1993).

Ambulatory care facilities. Ambulatory care facilities are of special importance because of the increase in patient users and the front-line health care worker status in the United States. Health care employers in outpatient settings should be aware of the risk of TB among their patient population, especially those who have both HIV and TB infections. Infection control policies should be developed accordingly.

Those who are HIV-positive or are otherwise at risk for contracting TB should receive a tuberculin skin test, and the results should be noted in the patient's medical record. Tuberculosis diagnostic procedures should be initiated if signs and symptoms of tuberculosis develop.

Ambulatory patients who have pulmonary symptoms of uncertain etiology should be instructed to cover their mouths and noses when coughing or sneezing; they should spend a minimum time in common waiting areas. Personnel who are the first point of contact in facilities serving patients at risk for tuberculosis should be trained to recognize, and bring to the attention of the appropriate person, any patients with symptoms suggestive of tuberculosis, such as a productive cough of greater than three weeks' duration, especially when accompanied by other tuberculosis symptoms such as weight loss, fever, fatigue, or anorexia.

Ventilation systems in clinics serving patients who are at high risk for tuberculosis should be designed and maintained to reduce tuberculosis transmission. This is particularly important if immunosuppressed patients are treated in the same or a nearby area. In some settings, enhanced ventilation or air disinfection techniques (HEPA filters or indirect or contained ultraviolet germicidal irradiation [UVGI] [CDC, RR-13, p.88, 1994d]) may be appropriate for common areas such as waiting rooms. Air from clinics serving patients at high risk for tuberculosis should not be recirculated unless it is first passed through an effective decontamination system such as a HEPA filtration system.

In outpatient settings where cough-inducing procedures are carried out, infection control precautions for TB (respiratory precautions) should be implemented. A special concern is the drug treatment facility. TB patients who have substance abuse problems are likely to be noncompliant with TB therapy, and may develop drug-resistant disease as a result (Raviglione et al, 1995).

Emergency medical services. Emergency medical services (EMS) personnel should be included in a respiratory program and in a comprehensive tuberculin skin-testing program with a baseline test and follow-up testing according to risk assessment (CDC, 1994b).

EMS personnel and others who provide patient services should ensure that a surgical mask is placed over the patient's mouth and nose (if possible) when a patient who has confirmed or suspected TB is being transported. Because of the lack of engineering controls in the transport vehicle, and because administrative controls cannot be ensured under such circumstances, EMS personnel are advised to wear respiratory protection as well.

Laboratory. Exposure to laboratory-generated aerosols is the most insidious hazard. Sputa and other clinical specimens from suspected or known cases should be handled with appropriate precautions to preclude the release of infectious droplets and spatter. Organisms can survive in heat-fixed smears and can be aerosolized during the preparation of frozen sections and the manipulation of liquid cultures. In a practical approach to control aerosol hazards in laboratories, Gilchrist et al (1994) provided guidance on the personal protective equipment and the safe procedures necessary for handling liquid-amplified cultures, as opposed to those needed for the less hazardous work of planting primary clinical specimens on solid media.

In 1997 the CDC published proposed guidelines for working with *M. tuberculosis* in laboratories (CDC/NIH, 1997). The goal of this document was to present health and safety information, to be used in conjunction with the BMBL (CDC/NIH, 1999), for those persons working with *M. tuberculosis* in laboratories. This document was a proposal; public comment was collected but a revised final draft has not been published. With regards to respiratory protection, the CDC proposed the worker

wear an air-purifying respirator with either N100 or HEPA filters during collection of sputum specimens in an open laboratory. The guidelines also recommended that all personnel working with *M. tuberculosis* in BSL-3 laboratories wear an air-purifying respirator with N95 filters.

Bioterrorism

The threat of the intentional release of a biological agent has increased, as reflected in congressional hearings, research studies, government warnings, and commentaries as well as confirmed exposures to and infections with *Bacillus anthracis* (the agent of anthrax) in late 2001 (Simon, 1997; Macintyre et al, 2000; CDC, 2001a,b). Biological terrorism has been defined as the deliberate use of a biological agent to harm civilian populations (Lillibridge et al, 1999; Macintyre et al, 2000) while biological warfare is the deliberate induction of disease in humans, animals, or plants as a hostile act (Pearson, 1997). The designation of chemical and biological weapons, along with nuclear materials and high explosives, as weapons of mass destruction emphasizes the potential catastrophic effects biological agents may have (Macintyre et al, 2000).

Natural and unintentional exposures of workers to infectious agents and biological toxins are far more likely than deliberate exposure, thus, the threat posed by biological terrorism must be kept in perspective (Macintyre et al, 2000). Until October 2001, no successful biological attack with an aerosolized agent had been made in the United States, although other crimes (biocrimes) and hoaxes had occurred (Kortepeter & Parker, 1999; Macintyre et al, 2000). The intentional distribution of *B. anthracis* and subsequent inhalation and cutaneous infections as well as many false alarms have tested the ability of local agencies to handle a bioterrorism event (Bryan & Fields, 1999; CDC, 2001a,b). Targets of anthrax and other biological threats have included government buildings and officials, post offices, courthouses, financial institutions, clinics and hospitals, anti-abortion groups, nightclubs, religious institutions, schools, retail establishments, office buildings, and news media offices.

Early recognition of a biological event would allow a rapid response that potentially could save lives, increase the possibility of apprehending the perpetrators, and deny terrorists their goal of creating panic and crisis (Franz et al, 1997; Simon, 1997; McDade & Franz, 1998). Preparations for a bioterrorist attack have the additional benefit of improving the ability of public health agencies to address infectious disease outbreaks, food safety concerns, and environmental hazards (Bryan & Fields, 1999). These preparations overlap with ongoing activities to meet the threats posed by new and reemerging infectious diseases (McDade & Franz, 1998; CDC, 2000). Industrial hygienists and environmental health professionals can contribute to efforts to anticipate biological hazards and can advise on appropriate protection for emergency personnel and medical staff who would respond to a biological attack.

BIOLOGICAL AGENTS AND TREATMENTS

Biological agents of potential use in bioterrorism include bacteria, viruses, and toxins of microbial, plant, or animal origin (Franz et al, 1997; Kortepeter & Parker, 1999). The Centers for Disease Control and Prevention (CDC) has focused on agents that might have the greatest impact on U.S. health and security and has defined three categories of biological agents with the potential to be used as weapons, based on ease of dissemination or transmission, potential for major public health impact (e.g., high mortality), potential for disrupting health care delivery, potential for causing public panic and social disruption, and requirements for public health preparedness (Table 14–G) (CDC, 2000, 2001b). Current listings of critical biological and chemical agents may change as new information becomes available. The CDC currently regulates the transfer of these select agents under 42 *CFR* 72 – the interstate shipment of etiologic agents. With some exceptions, persons transferring the agents listed in Table 14–G must register their facility with CDC and develop an agent transfer tracking system (U.S. PHS, 1996). Additional information about the registration program may be obtained from the CDC Office of Health and Safety Information System (Ohasis), see U.S. PHS 42 *CFR* 72.6 under regulations later in this chapter.

Rapid identification of the single or multiple agents used in a biological attack is critical to prescribing appropriate therapy for exposed persons. Active immunization or antibiotic prophylaxis may prevent illness if exposure to an infectious agent is expected and the treatment is administered before a person is exposed (Franz et al, 1997). After confirmed or suspected exposure, but before symptoms arise, postexposure prophylaxis (PEP) (such as active or passive immunization or antibiotic treatment) may ameliorate the symptoms of an infectious disease (CDC, 2001a). However, once an infection is established, health care providers can only diagnosis the disease and provide supportive care and treatment specific to the infection (Franz et al, 1997).

RELEASE OF BIOLOGICAL AGENTS

Biological weapons are characterized by low visibility, high potency, and relatively easy delivery (for example, release in crowded areas of a building, through a ventilation system, or via letters or packages) (Danzig & Berkowsky, 1997). Biological agents differ in the dose required, the time from exposure to symptom onset, and the type of disease they cause, but all can be dispersed in aerosols of approximately 1–5 μm diameter. Particles of this size may remain suspended for long periods and penetrate to the distal bronchioles and terminal alveoli (Franz et al, 1997). For infectious agents, exposure routes other than inhalation (for example, oral or percutaneous) are considered less important than the respiratory route in the context of the strategic use of biological agents as weapons (Franz et al, 1997). Terrorists may

Table 14–G. ***Critical Biological Agents***

Category A

The U.S. public health system and primary health-care providers must be prepared to address varied biological agents, including pathogens that are rarely seen in the United States. High-priority agents include organisms that pose a risk to national security because they:

- ➢can be easily disseminated or transmitted person-to-person;
- ➢cause high mortality, with potential for major public health impact;
- ➢might cause public panic and social disruption; and
- ➢require special action for public health preparedness

Agents include:

- ➢Variola major (smallpox);
- ➢*Bacillus anthracis* (anthrax);
- ➢*Yersinia pestis* (plague);
- ➢*Clostridium botulinum* toxin (botulism);
- ➢*Francisella tularensis* (tularemia);
- ➢filoviruses - Ebola hemorrhagic fever, Marburg hemorrhagic fever; and
- ➢arenaviruses - Lassa (Lassa fever), Junin (Argentine hemorrhagic fever) and related viruses.

Category B

Second highest priority agents include those that:

- ➢are moderately easy to disseminate;
- ➢cause moderate morbidity and low mortality; and
- ➢require specific enhancements of the U.S. CDC's diagnostic capacity and enhanced disease surveillance.

Agents include:

- ➢*Coxiella burnetti* (Q fever);
- ➢*Brucella* species (brucellosis);
- ➢*Burkholderia mallei* (glanders);
- ➢alphaviruses - Venezuelan encephalomyelitis, eastern and western equine encephalomyelitis;
- ➢ricin toxin from *Ricinus communis* (castor beans);
- ➢Epsilon toxin of *Clostridium perfringens*; and
- ➢*Staphylococcus enterotoxin B.*

A subset of List B agents includes pathogens that are food-borne or waterborne. These pathogens include but are not limited to:

- ➢*Salmonella* species,
- ➢*Shigella dysenteriae*,
- ➢*Escherichia coli* O157:H7,
- ➢*Vibrio cholerae*, and
- ➢*Cryptosporidium parvum*.

Category C

Third highest priority agents include emerging pathogens that could be engineered for mass dissemination in the future because of:

- ➢availability;
- ➢ease of production and dissemination; and
- ➢potential for high morbidity and mortality and major health impact.

Agents include:

- ➢Nipah virus,
- ➢hanta viruses,
- ➢tickborne hemorrhagic fever viruses,
- ➢tickborne encephalitis viruses,
- ➢yellow fever, and
- ➢multidrug-resistant tuberculosis.

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attempt to contaminate food in restaurants or supermarkets, but large water supplies have not been considered attractive targets due to the large amount of an agent that would be required and the water purification procedures used in most U.S. cities (Simon, 1997).

RECOGNITION OF A BIOAGENT RELEASE

Infectious diseases occur as spontaneous epidemics of known, endemic diseases or of new or reemerging diseases. Outbreaks have also resulted from accidents in laboratories and other workplaces and may follow an intentional attack with a biological agent (Pavlin, 1999). The following clues have been suggested to identify an outbreak that resulted from an attack: (a) a large epidemic with greater case loads and more rapid onset than expected; (b) more severe disease than expected or an unusual exposure route; (c) a disease that is unusual for a given geographic area, found outside the normal transmission season, or in the absence of a normal vector; (d) multiple simultaneous epidemics of different diseases; (e) animal as well as human cases; (f) unusual strains or variants of an organism or ones with uncommon antimicrobial resistance patterns; (g) different attack rates in certain areas (for example, higher rates inside a building if the agent was released indoors and lower rates in a sealed building if the agent was released outdoors); and (h) claims or evidence of agent release (Franz et al, 1997; Pavlin, 1999; CDC, 2001b). The CDC maintains routine infectious disease surveillance systems, provides reference laboratory diagnosis and epidemiological support, disseminates public health information, issues quarantine measures, and provides expert advice on worker health and safety (McDade & Franz, 1998). CDC can assist public health officials with decision making if a threat occurs alleging the use of a biological agent (CDC, 1999) and can deploy public health response teams to assist with agent identification and consult on medical management and disease control (Lillibridge et al, 1999; CDC, 2000). The CDC emergency response telephone number is (770) 488-7100 and information about responding to bioterrorism is available at *http://www.bt.cdc.gov*.

Unlike some chemical agents, aerosolized biological agents generally do not have warning properties to alert persons who were exposed in an unannounced or unrecognized attack (Simon, 1997). While chemical agents typically lead to acute symptoms in persons near the site of exposure, diseases resulting from infectious biological agents have incubation periods of days. A delay of hours or days in symptom onset could mean that affected persons have dispersed widely before becoming ill (Tucker, 1997). Thus early detection of a covert attack with a biological agent is problematic and would rely on existing public health systems to notice a suspicious disease outbreak in time to initiate effective treatment (Tucker, 1997). Therefore, rather than a paramedic, it could be a physician or laboratory technician who first encounters evidence of a biological attack (Franz et al, 1997).

RESPONSE TO A BIOAGENT RELEASE

The components of an epidemiological investigation of any disease outbreak (natural or artificial) are (a) documentation of who is affected; (b) identification of possible sources and routes of exposure; (c) recording of signs and symptoms of disease; and (d) rapid identification of the causative agent (Franz et al, 1997). It was anticipated (and recent events have confirmed) that public health nurses, disease investigators, environmental health specialists, and other state and local health department employees will carry out many of the tasks of responding to a bioterrorism attack (Bryan & Fields, 1999). Key elements of an effective response plan include prompt recognition of the incident, staff and facility protection, decontamination and triage of potentially exposed persons, medical therapy, and coordination with external emergency response and public health agencies (IOM, 1999; Macintyre et al, 2000).

CDC has published interim guidelines on the management of bioterrorism threats (based on experience with anthrax episodes) (CDC, 1999) and a strategic plan for terrorism preparedness and response (CDC, 2000). CDC and the Association for Professionals in Infection Control and Epidemiology (APIC) have written a plan specifically for healthcare facilities (APIC, 1999; English, 1999). The guidelines direct that the proper authorities be notified immediately if release of a biological agent is threatened, suspected, or known to have occurred (CDC, 1999). In most cases, the local emergency response system is activated by dialing 911 or by contacting local law enforcement authorities. Local and state public health authorities and the local field office of the Federal Bureau of Investigation (FBI) also should be notified. The FBI has lead responsibility for crisis management for all cases of domestic terrorism and coordinates the collection of evidence. Crisis management involves resolution of hostile situations and the investigation and preparation of a criminal case for prosecution under federal law (Tucker, 1997). The Federal Emergency Management Agency (FEMA) is the lead agency for the coordination of federal assistance to state and local governments, including emergency relief to affected individuals and businesses, decontamination of the affected area, and measures to protect public health and safety and to restore essential government services (FEMA, 1999). Even for a domestic incident, it is unlikely that the response would be left entirely to local law enforcement and health officials, the FBI, FEMA, and the U.S. Public Health Service (Danzig & Berkowsky, 1997). The military has assisted civilian agencies given its resources, capabilities, and expertise (Danzig & Berkowsky, 1997).

Some civilian-based protocols have been established by the U.S. Public Health Service (U.S. PHS, 1997) and the Working Group on Civilian Biodefense (Henderson et al, 1999, Inglesby et al, 1999). Consultation also is available through the National Response Center at (800) 424-8802 (Macintyre et al, 2000). Some self-described expert consultant groups offer risk analysis and training in emergency response and some programs market equipment packages, but no large scale exercise or response experience has validated these programs (Macintyre et al, 2000). The Institute of Medicine (IOM, 1999) has published their assessment of existing research, development, and technology information on (1) the detection of potential chemical and biological agents and (2) the protection and treatment of the targets of attack and health care providers. This report also provides specific recommendations for priority research and development.

Decontamination. Decontamination of persons exposed to biological agents (to lessen the effects of primary exposure and prevent secondary exposure) may be necessary but is considered to be less important than with chemical agents. Exposure to mycotoxins may call for decontamination procedures similar to those used for chemical agents (Hurst, 1997; Macintyre et al, 2000), but reaerosolization of infectious particles is considered unlikely to any great degree (APIC, 1999; Keim & Kaufmann, 1999; Macintyre et al, 2000). Thus, decontamination following exposure to an infectious agent could be as simple as showering and changing clothes. In the past, a biocide to neutralize biological agents has been recommended (for example, a 0.5 percent solution of hypochlorite). However, the lack of clear data on the safety and efficacy of bleach decontamination suggests that it should be avoided, especially if soap and water are immediately available (Macintyre et al, 2000). Biological agents may pose only a temporary risk to the environment or to persons not directly exposed because of the usually rapid degradation of the organisms in the environment and difficult reaerosolization (Birenzvige, 1992; Hurst, 1997; Macintyre et al, 2000).

Personal Protective Equipment. Health care professionals and laboratory personnel may need physical protection when dealing with the victims of a biological attack, and autopsy and interment of remains could present unusual hazards (Franz et al, 1997; IOM, 1999). Persons caring for potentially contaminated individuals should be outfitted properly in personal protective equipment (PPE). Level D protection (standard work clothes) plus latex gloves, eye splash protection, and N-95 respirators (used in many places for protection against *M. tuberculosis*) are considered to be adequate (Eitzen et al, 1998; Anonymous, 1999; Macintyre et al, 2000). A high-efficiency particulate air (HEPA) respirator could be added if aerosols may be generated. If the agent class for a sudden release cannot be identified, Level C PPE is recommended, that is, a nonencapsulated, chemical-resistant suit, gloves, and boots and a full-face air purifying respirator with an organic vapor/HEPA filter cartridge (Macintyre et al, 2000).

When collecting or handling clinical specimens, laboratory personnel should (1) use Biological Safety Level II (BSL-2) or Level III (BSL-3) facilities and practices when working with clinical samples considered potentially infectious; (2) handle all specimens in a BSL-2 laminar flow hood

with protective eyewear (e.g., safety glasses or eye shields), use closed-front laboratory coats with cuffed sleeves, and stretch the gloves over the cuffed sleeves; (3) avoid any activity that places persons at risk for infectious exposure, especially activities that might create aerosols or droplet dispersal; (4) decontaminate laboratory benches after each use and dispose of supplies and equipment in proper receptacles; (5) avoid touching mucosal surfaces with their hands (gloved or ungloved), and never eat or drink in the laboratory; and (6) remove and reverse their gloves before leaving the laboratory and dispose of them in a biohazard container, and wash their hands and remove their laboratory coat (CDC, 2001b).

Role of Health and Safety Professionals. The CDC strategic plan includes collaboration with professional societies and the manufacturers of safety and medical equipment (CDC, 2000). The skills and training that industrial hygienists and environmental health, infection control, and biosafety professionals use to handle work-related and environmental diseases may help responders to detect, investigate, identify, and manage a civilian bioterrorist threat. Industrial hygienists and environmental health professionals are familiar with the use of PPE, dilution and exhaust ventilation, decontamination procedures, environmental sampling, and physical safety and security. Effective risk communication following a threat or event is of critical importance to disseminate accurate information and minimize rumors (Holloway et al, 1997). Employers and building operators should assess their vulnerability in terms of attracting attack and their ability to respond. Prior identification of the appropriate offices or agencies to contact facilitates notification in the case of a threat or suspicion of a release of a biological agent (Franz et al, 1997; Macintyre et al, 2000).

Legionellosis

BACKGROUND

Legionellosis is an acute bacterial disease with two clinically and epidemiologically distinct manifestations: Legionnaires' disease and Pontiac fever (Chin, 2000 pp 281–283). Legionnaires' disease (Legionnaires' pneumonia) is a pulmonary infection, whereas Pontiac fever (nonpneumonic legionellosis) is an inflammatory disease. Respectively, symptoms appear five to six days and 23 to 48 hours following exposure. Both diseases begin with anorexia, malaise, myalgia, and headache followed by a rapidly rising fever and chills (Breiman & Butler, 1998; Chin, 2000, pp 281–283). With Legionnaires' disease, a chest film often shows patchy or focal areas of consolidation that may progress to respiratory failure. The diagnosis and treatment of Legionnaires' disease are described elsewhere (Breiman & Butler, 1998; Winn, 1999). Pontiac fever is a self-limited flu-like illness that may represent a reaction to inhaled antigens rather than bacterial invasion (Breiman & Butler, 1998; Chin, 2000, pp 281–283).

Cases of legionellosis have been reported from North and South America, Australia, Africa, and Europe (Chin, 2000, pp 281–283). The majority of legionellosis cases are sporadic, with only approximately four percent related to outbreaks (Breiman, 1993; Marston et al, 1993). A legionellosis outbreak has been defined as the occurrence of two or more confirmed or probable cases in a limited time period (weeks to months) and geographic region (a building, area within a building, or up to several kilometers around a potential source) (ASTM, 1996). Guidance has been published on investigating potential legionellosis outbreaks (ASTM, 1996; Freije, 1996; CDC, 1997b). Brief, explosive, and prolonged outbreaks of Legionnaires' disease have been documented. The former occur most often in summer in association with a point source, such as a contaminated cooling towers or evaporative condensers (Breiman & Butler, 1998). Prolonged outbreaks in hospitals and hotels have been attributed to contaminated potable water. Pontiac fever is recognized solely in its epidemic form (sporadically occurring cases probably would be misclassified as influenza or other viral syndrome) (Breiman & Butler, 1998; Winn, 1999).

Subclinical *Legionella* infections likely are frequent given the worldwide occurrence of antibodies in the absence of recognized episodes of pneumonia. The prevalence of antibodies has ranged from 5 to 30 percent, although some positive findings may be due to cross reactions with other microorganisms (Breiman & Butler, 1998; Winn, 1999). Some surveys have documented higher antibody titers in groups with potentially greater risks for exposure and infection than the general population (Winn, 1999), and Legionnaires' disease has been associated with travel and recreational use of whirlpool spas (Dworzack, 1999; Collins et al, 1997). However, there does not appear to be a consistent correlation with particular occupational or recreational exposures (Winn, 1999).

Conditions such as other illness may predispose persons who are exposed to legionellae to infection. Recognized risk factors include age greater than 50 years, cigarette smoking, diabetes mellitus, chronic lung or cardiovascular disease, renal disease, and immune suppression caused by underlying disease or therapy (Chin, 2000, pp 281–283; Breiman & Butler, 1998; Winn, 1999). These factors increase a person's risk not only for acquiring Legionnaires' disease but also for dying as a result of infection (CDC, 1997). Attack rates in outbreaks of Legionnaires' disease are low (<5%), but the case-fatality rate for persons who require hospitalization for the infection may reach ~40 percent. Nosocomial and community-acquired Legionnaires' disease requiring hospitalization have been estimated to represent one to five percent of all pneumonias (Breiman, 1993; Winn, 1999), and the national incidence of community-acquired Legionnaires' disease has been estimated at 17,000 to 23,000 cases annually (Marston et al, 1994). Extreme fatigue and chronic respiratory symptoms may persist for several months after recovery from acute infection (Breiman & Butler, 1998). In contrast, Pontiac fever affects a wider range of persons and attack rates typically are high (~95%) but patients recover spontaneously in two to five days.

THE AGENT

Legionellae are poorly staining, gram-negative, rod-shaped bacteria. Legionellae are aerobic, somewhat fastidious in their growth requirements, and relatively slow growing in culture. The bacteria do not survive desiccation and do not form spores. The motile cells measure 0.3-0.9 × 1.5-5 μ. (Winn, 1999) but may grow as long filaments in laboratory culture (Fliermans, 1995). Approximately 39 species and 61 serogroups have been recognized (Dennis et al, 1993). *L. pneumophila* alone has some 18 serogroups, but *L. pneumophila* serogroup 1 accounts for more than 75 percent of documented cases of legionellosis (Breiman & Butler, 1998). Serogroups 4 and 6 also are commonly associated with legionnaires' disease. Other species associated with clinical infections include *Legionella bozemanii*, *Legionella dumoffii*, *Legionella feeleii*, *Legionella longbeachae*, and *Legionella micdadei*. Pontiac fever also is most frequently caused by *L. pneumophila* serogroup 1 as well as *Legionella anisa*, *L. feeleii*, and *L. micdadei*. Possible explanations for the manifestation of two disease syndromes caused by the same bacteria include differences in host susceptibility and the inability of some legionellae to multiply in human tissue (for a variety of reasons, including bacterial virulence, host range, and viability) (Fields, 1997). Pontiac fever may represent a toxic or inflammatory response to legionellae or other antigens (for example, amebic antigens inhaled with the bacteria). This theory is based on the observation that Pontiac fever does not progress to systemic infection (Breiman & Butler, 1998).

SOURCES

Legionellae are indigenous microorganisms associated almost exclusively with surface and potable waters and other moist environments (Fliermans, 1995; APHA, 1998; Winn, 1999). Humans have long coexisted with these bacteria, and only recently has industrial technology provided them a means to cause infections (Fields, 1997). Legionellae frequently are present in low numbers in drinking water supplies, apparently without causing problems (Hoage & Breiman, 1991; CDC, 1997b; Fields, 1997). Surveys have found legionellae in large percentages of tested hospitals, large buildings, and residences, often in hot-water supplies and cooling waters for heat-transfer systems (CDC, 1997b). Legionellae have been isolated by culture in ~40 percent of freshwater environments and detected by polymerase chain reaction detection in up to 80 percent of such sites (Fields, 1997). Hot-water systems, water-cooled heat-transfer systems, humidifiers, whirlpool spas, respiratory therapy devices, and decorative fountains have been implicated epidemiologically in legionellosis outbreaks (Breiman & Butler, 1998; Chin, 2000, pp 281–283). These sources are of two general types (Breiman, 1993; Fields, 1997)

- Contaminated potable water sources, such as showers, faucets, and respiratory therapy equipment
- Contaminated nonpotable water sources, such as cooling towers, evaporative condensers, whirlpool spas, decorative fountains, ultrasonic mist machines, humidifiers, and water-based cutting fluids

Factors known to enhance legionellae colonization of man-made water environments include warm temperature (25-45 C), suitable pH (2.5–9.5), water stagnation followed by agitation, and the presence of other organisms, sediment, and scale. Protozoa appear to be natural hosts for legionellae, and environmental protozoa may be critical for bacterial survival and growth (Fields, 1997). Legionellae multiply within single-cell protozoans in the environment and within alveolar macrophages in humans. Bacteria inside protozoa may be protected from biocides, desiccation, and other environmental stresses.

TRANSMISSION

There is no evidence that Legionnaires' disease or Pontiac fever is transmitted other than by inhalation of aerosolized bacteria from environmental sources or by aspiration of contaminated water into the lower respiratory tract (CDC, 1997b; Fields, 1997). Studies have indicated that aerosols from contaminated cooling towers may carry bacteria hundreds of meters and perhaps further (Addiss et al, 1989). Human-to-human transmission has not been observed and there have been no documented laboratory infections (Winn, 1999). Therefore, the usual safety precautions are adequate for laboratory work not likely to generate aerosols. Legionellae infections that do not fit the clinical syndromes of Legionnaires' disease or Pontiac fever also have been reported in immunosuppressed persons and include endocarditis, peritonitis, and skin and soft tissue infections (Breiman & Butler, 1998). These extrapulmonary infections occur via metastatic spread of bacteria and direct contact with contaminated waters (Winn, 1999).

SOURCE SAMPLING

Sampling of suspected sources for the presence of legionellae has proven useful in outbreak investigations, to study the ecology of these bacteria, and to evaluate the efficacy of various prevention measures (Fields, 1997; APHA, 1998; Breiman & Butler, 1998; Winn, 1999). However, the value of routine water sampling (unrelated to outbreak investigations) has not been demonstrated and, consequently, is controversial (ASTM, 1996; Freije, 1996; Millar et al, 1997; Breiman & Butler, 1998; Winn, 1999). The sources of community-acquired infections are difficult to identify and the appropriate response to finding legionellae is unclear given their ubiquity and the observation that they rarely cause disease (Fields, 1997; Breiman & Butler, 1998). Thus, CDC recommends aggressive maintenance and disinfection protocols for devices known to transmit legionellae but does not recommend regularly scheduled microbiological testing in the absence of legionellosis or as a substitute for proper maintenance (Hoage & Breiman, 1991; Fields, 1997). Testing programs have been developed for high-risk facilities, such as hospitals (Freije, 1996; ACHD, 1997; CDC, 1997b). These plans include suggestions for environmental parameters to monitor, record keeping, where to collect sam-

ples and how many samples to collect, and the frequency for conducting various tests. Freije (1996) also provides cost estimates for various testing and treatment protocols.

Collection of 0.5–1 L of water allows concentration of the sample, if necessary, and the application of various treatments that enhance isolation of legionellae. Water samples should be collected into clean, sealable containers. Samples should include sediment and swabbings or scrapings of the walls of water containers and fixtures (for example, hot-water tanks and shower heads). Chlorinated water should be treated with sodium thiosulfate (0.5 mL of 0.1 $Na_2S_2O_3$ per liter). More detailed directions for sample collection and handling are available elsewhere (ASTM, 1996; Freije, 1996; Fields, 1997; APHA, 1998). Environmental samples should be transported to the laboratory in insulated containers that protect the materials from extreme heat or cold. Samples should be processed within 24 h of collection or refrigerated until processed (Fields, 1997; APHA, 1998).

Methods for the recovery of bacterial pathogens from water have not changed significantly in the past 30 years (APHA, 1998). Legionellae are detected by isolation of the bacteria in culture and direct detection of bacterial antigens and nucleic acids. Procedures for culture, direct fluorescent antibody staining, and polymerase chain reaction detection are described in standard references (CDC, 1994a, 1997; Fliermans, 1995; Fields, 1997; APHA, 1998; Winn, 1999). The latter two detection methods may be more sensitive than culture, but they do not distinguish between viable and nonviable bacteria. Culture isolation often is preferred because it identifies bacteria capable of causing infection, and environmental culture isolates can be typed for comparison with clinical isolates (Breiman & Butler, 1998; Winn, 1999). A close match between a legionellae isolated from the environment and a clinical specimen may identify the source of a person's exposure and the water system in need of attention. Criteria for the interpretation of culture results for potential exposure of low-risk persons have been proposed for cooling towers, evaporative condensers, potable water, humidifiers, and foggers (Freije, 1996; Morris & Shelton, 1998). The criteria include recommendations for remedial actions and time frames for follow-up testing and remediation.

AIR SAMPLING

Viable legionellae have been collected from air onto agar-based culture medium or into liquid for transfer to growth media (Breiman et al, 1990; CDC, 1994a). Air sampling has demonstrated the presence of airborne legionellae associated with suspected sources and helped define the roles of devices such as showers, faucets, and evaporative condensers in disease transmission (Fields, 1997). However, examination of source samples is considered more efficient than air sampling to identify potential inhalation exposure to legionellae (Breiman, 1993, 1996; Freije, 1996; Fields, 1997). Air sampling is relatively insensitive at identifying viable legionellae, but assays not based on microorganism culture may detect even nonviable bacteria if present in sufficient numbers (AIHA, 1996a).

PREVENTION OF LEGIONELLOSIS

In 1983, Fraser developed a conceptual chain of causation to describe the events necessary for a legionellosis outbreak (Fraser, 1984).

- ➢ Legionella in an environmental reservoir
- ➢ Multiplication of the bacterium to high concentrations
- ➢ Bacterial dissemination
- ➢ The bacterium must be virulent for humans
- ➢ Inoculation of the bacterium at an appropriate site in a human host
- ➢ Exposed persons who are susceptible to infection by the legionellae

This scheme has served as a model for understanding the epidemiology of legionellosis as well as for developing prevention strategies (Breiman, 1993; Fields, 1997). Given the impossibility of eliminating legionellae from most water systems, disease prevention generally focuses on limiting bacterial multiplication and aerosolization. Development of a vaccine to prevent infection through active immunization has been explored (Horwitz et al, 1993; Breiman & Butler, 1998), but further development and use await a better understanding of the incidence of legionellosis and the populations at risk (Breiman, 1993).

Practices to control the multiplication of legionellae in potable water systems can be divided into routine maintenance and emergency decontamination (ACHD, 1997; Fields, 1997). The risk of legionellosis can be reduced through proper design and operation of ventilation, humidification, and water-cooled heat-transfer equipment. Appropriate maintenance includes regular use and cleaning and biocide treatment, where appropriate (for example, chlorination to achieve 1–2 mg/L of free residual chlorine at the tap). Some documents have suggested that outdoor air intakes be located no closer than a certain distance from possible sources of aerosolized legionellae (Shaughnessy et al, 1999). However, Fields (1997) concluded that data to support this recommendation are limited.

Breiman and Butler (1998) emphasized that interventions should be directed at both amebae and legionellae. Precautions specific to the prevention of legionellae multiplication in water systems include the following (Fliermans, 1995; ASTM, 1996; Freije, 1996; ACHD, 1997; CDC, 1997b; Fields, 1997; Millar et al, 1997; Shaughnessy et al, 1999):

- ➢ Keep hot water above 60 C (140 F) and cold water below 20 C (68 F); deliver water to taps at ≥50 C (122 F) and ≤20 C, respectively.
- ➢ Separate or insulate water lines to prevent heat transfer.
- ➢ Avoid tepid water systems (for example, deliver hot and cold water in separate lines and mix them at the point of use rather than in a warm water holding tank).
- ➢ Flush faucets and showers briefly before use; flush infrequently used water supply lines on a regular basis (for example, weekly or monthly).

Table 14–H. ***Definitions of Terms (ACGIH, 1999a; Appendix B)***

Bioaerosol: airborne particles that are living or originated from living organisms including microorganisms (culturable, nonculturable, and dead microorganisms) and fragments, toxins, and particulate waste products from all varieties of living things.
Biologically derived airborne contaminant: bioaerosols and the gases and vapors that organisms produce.
Biological contamination: the presence of (a) biologically derived aerosols, gases, and vapors of a kind and concentration likely to cause disease or predispose persons to adverse health effects, (b) inappropriate concentrations of outdoor bioaerosols, especially in buildings designed to prevent their entry, or (c) indoor biological growth and remnants of growth that may become airborne and to which people may be exposed.
Biological agent: a substance of biological origin that is capable of producing an effect (for example, an infection or allergic, irritant, inflammatory, or toxic response).

➢ Remove *deadlegs* in water systems (for example, disconnect and drain unused plumbing and equipment).

Additional recommendations for reducing the risks of legionellosis that also help prevent other problems associated with biological contamination include the following:

➢ Choose HVAC and water systems and other equipment of the best design and capacity for a facility's needs.
➢ Label equipment for easy identification.
➢ Keep up-to-date blueprints or schematic drawings that identify control equipment and access points.
➢ Operate and maintain (inspect, clean, and repair) equipment according to the manufacturer's recommendation.
➢ Outline responsibilities in writing and see that staff understand and are trained for their assignments.
➢ Deal with identified problems promptly.
➢ Outline emergency responses in writing and have important names and phone numbers readily available.
➢ Keep good records and see that reports are dated and signed.
➢ Seek expert advice when needed.

The CDC (1997) has published a procedure for emergency cleaning and disinfection of cooling towers and related equipment that may be contaminated with *Legionellae*. The principal methods for disinfecting potable water systems are (ASTM, 1996; Freije, 1996; CDC, 1997b):

➢ Heat flushing at temperatures above 70 C (>158 F)
➢ Hyperchlorination (≥10 mg/L of free residual chlorine)
➢ Physical cleaning of hot water tanks.

The CDC (1996) also has issued recommendations for minimizing the transmission of Legionnaires' disease from whirlpool spas. Personal protective equipment has been suggested for persons examining equipment, such as cooling towers, associated with Legionnaires' disease outbreaks (ASTM, 1996; Freije, 1996). These include disposable garments, slip-proof footwear, and eye protection when examining areas that are wet, potentially contaminated, or recently treated with biocides, disinfectants, detergents, or other chemicals. An N95 or HEPA respirator is recommended for work near potentially contaminated equipment that might generate aerosols. A combination respirator may be needed for protection from aerosols and gases or vapors (for example, chlorine). Section III, Chapter 7 of the OSHA *Technical Manual* describes investigation of possibly work-related legionellosis.

Building-Related Bioaerosol Problems

Recognition is increasing of the potential adverse health effects of inhaling particles, gases, and vapors from plants, animals, and microorganisms. Airborne particles and volatile compounds from living and decomposing biological matter are abundant outdoors and enter buildings via natural and mechanical ventilation. Indoor sources of particles of biological origin include humans, the materials they bring into buildings, and the activities conducted there, but of equal importance is the indoor growth of microorganisms and arthropods. The biological agents found in office and commercial buildings overlap those common in agricultural and manufacturing environments. However, the air concentrations in the former environments typically are orders of magnitude lower whereas the workforce is more diverse in terms of age range, general health status, and the mental and physical requirements of their jobs.

The American Industrial Hygiene Association (AIHA) (1996) has defined bioaerosols as airborne particles originating from microbial matter, which together with particles from plants and animals forms organic dusts. However, as the American Conference of Governmental Industrial Hygienists (ACGIH) uses the term, particles from plants and animals are also bioaerosols (Table 14–H). These particles along with gases and vapors from various organisms are natural components of indoor and outdoor environments but may be considered contaminants when their presence in buildings causes adverse health effects, disturbs occupant comfort, reduces worker productivity, or damages materials.

BUILDING-RELATED ILLNESSES AND SYMPTOMS

Specific building-related illnesses are diagnosable conditions whose causes can be attributed to indoor exposure to a chemical, physical, or biological agent (Fischman, 1997; ACGIH, 1999b). Building-related illnesses have known etiology and frequently are accompanied by documentable physical signs and laboratory findings. For example, the following building-related illnesses are known to be due to biological agents: (a) infections, such as acute viral infections, Legionnaires' disease, and tuberculosis; (b) immunologically mediated diseases, such as allergic rhinitis, sinusitis, asthma, and hypersensitivity pneumonitis; and (c) inhalation fevers, such as humidifier fever, Pontiac fever, and other febrile, flu-like illnesses. Many chemical and physical agents also can cause building-related illnesses, for example, carbon monoxide, volatile organic compounds, and glass fibers.

The terms *sick-building syndrome* and *tight-building syndrome* have been used when building occupants experience eye, nose, and throat irritation, headache, fatigue, and other discomfort in a building. In this chapter, these complaints will be referred to as nonspecific building-related symptoms because they are linked with time spent in a building but cannot be associated with a well-defined agent. Nonspecific building-related symptoms have many causes (physical, chemical, and psychosocial as well as biological), and the contributions to worker performance and comfort of factors related to the building, the host, and job demands also must be considered. Various bacterial and fungal agents have been proposed to explain some nonspecific building-related symptoms, for example, endotoxin, peptidoglycans, mycotoxins, and microbial volatile organic compounds. Some proportion of nonspecific building-related symptoms likely are early stages of specific, unrecognized illnesses, which left unchecked could progress to building-related illnesses (Hodgson, 1994).

Infectious diseases that may be associated with exposures in office and commercial buildings include acute respiratory infections, varicella (chicken pox), measles, tuberculosis, and Legionnaires' disease. For all but the last disease, the infectious agents are transmitted through the air from person to person. The agent of Legionnaires' disease originates from environmental sources of water containing the bacteria that becomes airborne when the water is aerosolized. Tuberculosis and Legionnaires' disease are described in more detail in other sections of this chapter.

Persons allergic to pollen from outdoor plants generally find some relief when indoors. Common allergens for which exposures typically are higher indoors include arthropods (dust mites and cockroaches), birds, and mammals (cats, dogs, and rodents). Bacterial, fungal, and amebic allergens may be found in indoor or outdoor air, but indoor concentrations may be higher thus indoor exposures greater. People's responses to airborne allergens depend on genetic factors, prior exposures, and the duration and intensity of subsequent exposures (Rose, 1999). Immune responses to indoor aeroallergens may involve the upper or lower airways and include familiar responses, such as allergic asthma, rhinitis, and sinusitis and atopic dermatitis, as well as the less common allergic mycosis (most often allergic aspergillosis) and hypersensitivity pneumonitis (Hodgson, 1994; Balmes & Scannell, 1997; ACGIH, 1999b; Rose, 1999).

Inhalation fevers, other inflammatory responses to bioaerosols, and responses to inhaled biological toxins are discussed in the following sections on organic dust, mycotoxins, endotoxin, and *Pfiesteria*. Investigations of specific building-related illnesses often are fairly straightforward because a clear diagnosis has been made, the causative agent (or class of agents) is known (an infectious, allergenic, irritant, or inflammatory agent), and sources of the agent can be anticipated and examined. It may be more difficult to identify the cause of a nonspecific building-related symptom along with the source of the agent, the route of exposure, and the appropriate measures to minimize exposure.

INVESTIGATION OF BUILDING-RELATED SYMPTOMS

Typical indoor sources of biological agents are (a) people, who shed bacteria and viruses, (b) building materials, furnishings, and ventilation system components that provide a suitable environment for organism survival and growth, (c) accumulations of biological materials on indoor surfaces, and (d) animals that shed allergens (ACGIH, 1999c). Many investigations of problem buildings are based on the development and testing of hypotheses—carefully formulated, logical answers or explanations. Investigators combine available environmental, epidemiological, medical, and toxicological evidence to develop hypotheses, then devise ways to check these theories to determine which are consistent with available information. Several checklists and protocols are available to guide building evaluations (EPA, 1994; Godish, 1995; Crandall & Sieber, 1996; ACGIH, 1999d; Morey, 1999; Burton, 2000). Section III, Chapter 2 of the OSHA *Technical Manual* describes investigation of indoor air quality (www.osha.gov).

ENVIRONMENTAL SAMPLING

The presence of biologically derived contaminants may be determined from air or source samples. Water, building materials and furnishings, settled dust, and surfaces are sources that may be tested in building-related illness and nonspecific building-related symptom investigations to identify contaminated materials and to evaluate the effectiveness of mitigation and remediation efforts (Dillon et al, 1999; Martyny et al, 1999). Testing is done to determine if organisms (for example, microorganisms or dust mites) have colonized the material and are actively growing as well as to identify surfaces where previously airborne particles have accumulated.

Typical bulk samples are settled dust collected with a vacuum device and sections of wallboard, pieces of duct lining, or segments of carpet cut from representative areas. Samples from intact surfaces (for example, tape lifts or vacuum samples from wood, plaster, metal, or vinyl surfaces) and porous materials (for example, vacuum samples from drapes or upholstered furniture) can identify whether materials are contaminated beyond background levels. Bioaerosols may be released from contaminated surfaces via natural spore discharge and disturbances that reaerosolize particles. Likewise, building occupants and clean-up workers may be exposed to biological agents through skin contact with contaminated surfaces and while handling contaminated porous materials.

Bioaerosols are collected from the air by three primary methods: inertial impaction onto an adhesive surface, inertial impaction in a liquid impinger or wetted cyclone, and filtration. The AIHA field guide provides descriptions of the most widely used bioaerosol samplers and instructions on their operation (AIHA, 1996a). Lists of instruments for

indoor air sampling, including bioaerosol samplers, have been published (Macher, 1998, 2000; Willeke & Macher, 1999), and several groups have summarized procedures for the collection and analysis of environmental samples for bacteria, fungi, amebae, viruses, endotoxin, other bacterial cell-wall components, fungal toxins, glucans, and allergens (AIHA, 1996; Ammann, 1999; Arlian, 1999; Burge & Ammann, 1999; Burge & Otten, 1999; Dillon et al, 1999; Milton, 1999; Otten & Burge, 1999a-c; Rose, 1999).

SAMPLING STRATEGY

Investigators collect air samples to characterize exposure to biological agents by measuring: (a) background or baseline air concentrations for comparison with samples from other locations, (b) air concentrations representative of worst-case or highest exposures, and (c) air concentrations representative of average or typical exposures (ACGIH, 1999e). The first type of sample is collected outdoors or in an area of a building where there is no history of water damage or visible microbial growth and in which the occupants have not been diagnosed with building-related illnesses and do not complain of nonspecific building-related symptoms. Samples collected under conditions that simulate the active movement of occupants and operation of a building's ventilation system (semi-aggressive sampling) may reflect the highest bioaerosol exposures that persons in a contaminated building may experience. Sampling without additional disturbances is used to represent exposures that occur at other times. Recommendations on where, when, and how many samples to collect are available (AIHA, 1996c-e; ACGIH, 1999e; Dillon et al, 1999; Gross & Morse, 2001 [Ch 15 Evaluation]).

SAMPLE ANALYSIS

Environmental samples are used qualitatively and quantitatively to: (a) identify biological agents and understand the environmental conditions that lead to their presence indoors, (b) demonstrate possible pathways by which bioaerosols and gases and vapors of biological origin may travel from environmental sources to workers, and (c) measure worker exposure to biological agents and learn about exposure-response relationships (ACGIH, 1999f). Culture-based methods and direct microscopic examination are the analytical procedures used most commonly to assess the extent of indoor microbial growth. Consequently, the largest databases on indoor fungi and bacteria are those reporting measurements of culturable and countable microorganisms. Investigators may use an analytical method for an indicator of a specific agent, such as the sampling for *Escherichia coli* as an indicator of contamination with raw sewage following a plumbing leak, the analysis of glucan or ergosterol as a measure of fungal biomass, or the detection of guanine as an indicator of dust mite presence. The term indicator also is used when referring to microorganisms or chemical markers whose detection may reflect the simultaneous occurrence or presence of the actual biological agents responsible for adverse health effects. For example, the detection of a particular fungus may be used to indicate that a particular allergen is present, and detection of high concentrations of peptidoglycans may be used to indicate the likely presence of elevated concentrations of bacteria. Nucleic acid probes, chemical assays, bioassays, and other analytical methods are used when specific organisms or biological agents are under investigation, such as *Legionella* spp, animal allergens, endotoxin, and fungal toxins.

INTERPRETATION OF DATA

The lack of exposure criteria for most biological agents precludes identifying excessive exposures solely by measuring air concentrations as is done for many chemical and physical agents. Therefore, assessments for bioaerosol exposures rely on visual inspections of buildings, tabulation of occupant symptoms, evaluations of building performance, sampling of potential environmental sources, and application of professional judgment. Several groups have attempted to develop numerical guidelines for the interpretation of bioaerosol measurements, but these seldom are based on health criteria, and the validity of broadly applying these concentration guidelines to all types of buildings and different climate zones is uncertain. Numeric guidelines are also subject to misinterpretation as recommended limits or goals that identify unsafe or unhealthy work environments. In particular, guidelines on the interpretation of environmental exposures to fungi have received a great deal of attention.

Several groups have published guidance on the interpretation of environmental samples for fungi (for example, the identification of specific fungal genera and species in air and source samples) (*Health Canada*, 1993, 1995; Samson et al, 1994; AIHA, 1996c; ISIAQ, 1996). These groups have emphasized that active fungal growth in indoor environments is inappropriate and may lead to exposure and adverse health effects, as outlined in the following suggestions for assessing problems in nonindustrial indoor environments (Burge & Otten, 1999):

- The presence of visible fungal growth confirmed by source sampling in occupied indoor environments is strong evidence that exposure may occur. The conditions leading to such growth should be corrected and the growth removed, using appropriate precautions.
- The presence of moldy odors in occupied indoor environments is strong evidence that fungal growth is occurring. Such growth should be located and confirmed by source sampling. The conditions leading to the growth should be corrected and the growth removed, using appropriate precautions.
- The persistent presence of water in indoor environments (except in places designed for the carriage or storage of water) is likely to lead to fungal growth. The conditions allowing such water to accumulate should be corrected.
- The presence of accumulations of organic debris, especially bird or animal droppings, is presumptive evidence of the

presence of fungal contamination. The conditions allowing the accumulation of such debris should be corrected and the debris removed, using appropriate precautions.

➢ Interpretation of source or air sampling data in the absence of any of the above conditions requires a sufficient number of samples to ensure that the results are not due to random chance.

Summary. Evaluating indoor environmental quality can be a challenging endeavor. There is little formal regulation in this area and, while some groups have recommended exposure limits for certain biological agents, few guidelines are based on health criteria or are enforceable (Rao et al, 1996). Some researchers have concluded that assessment of exposures through the measurement of specific biological agents is not especially useful (Hodgson, 1994). Instead, investigators are encouraged first to exhaust other approaches (such as medical evaluation of affected individuals and identification of their illnesses) as well as analysis and correction of deficiencies in building design, maintenance, and operation, before undertaking environmental sampling for biological agents to identify the causes of building-related symptoms.

Biological Hazards Associated with Noninfectious Agents

Various biological hazards are discussed in the following section.

ENDOTOXINS

The term *endotoxin* designates a class of lipopolysaccharide-protein complexes that are integral parts of the outer membranes of gram-negative bacteria (for example, species of *Aeromonas*, *Citrobacter*, *Enterobacter*, *Escherichia*, *Helicobacter*, *Klebsiella*, *Serratia*, and *Pseudomonas*) (AIHA, 1996d; Olenchock, 1997). Endotoxins are found in the environment in whole bacterial cells and fragments of cell membranes (Rietschel & Brade, 1992; Milton, 1996; Olenchock, 1997). This material is released into the environment during active bacterial growth and following disruption of cell membranes (Milton, 1996; Olenchock, 1997). Gram-negative bacteria and endotoxins are found widely in soil and water and on animals and plants. Endotoxin exposure has been studied in occupational settings, in particular, agricultural environments (where workers may be exposed to grains, silage, hay, straw, and animal bedding) and machining operations (where workers may be exposed to contaminated metal-working fluids). Other sources of occupational exposure are composted wood chips, stored timber, tobacco, and cotton dust. Workers in nonmanufacturing workplaces, such as office buildings and libraries, may be exposed to endotoxin if spray humidification systems contain gram-negative bacteria or other contaminated materials become aerosolized.

Endotoxin comprises a family of molecules called *lipopolysaccharides*, which consist of polysaccharide chains connected to a lipid. The lipid A portion is responsible for the majority of endotoxin's toxic properties (Rylander, 1994; Milton, 1996). In the environmental literature, the term lipopolysaccharides generally is reserved for purified preparations and is used in reference to the chemical characteristics or physical amount of the molecule in a sample (Milton, 1999). The term endotoxin denotes the naturally occurring material and is used when referring to the toxic activity or potency of environmental samples. Thus, exposure to endotoxin in organic dusts involves simultaneous exposure to bacterial proteins and other cell constituents (Rylander, 1994).

Health Effects

Endotoxin can cause fever and malaise, changes in white blood cell counts, respiratory distress, and shock (Milton, 1995). Most medical attention has focused on the toxicity of endotoxins in reaching the bloodstream from infections with endogenous gram-negative bacteria or those that enter the body via contaminated parenteral products. However, little endotoxin is detectable in the blood after inhalation exposure (Boehlecke & Jacobs, 1994). Local uptake of endotoxin in the respiratory system appears to account for the effects observed following inhalation exposure. The pulmonary macrophages are the primary targets for inhaled endotoxin where it induces a series of intracellular changes referred to as activation (Rylander, 1994; Olenchock, 1997).

Differences in the types and amounts of mediators that are generated, the time course, and cellular receptors lead to varying types and severities of organ damage (Olenchock, 1997; IOM, 2000). Endotoxin also can act as an adjuvant and boost responses to inhaled antigens (Rylander, 1994). This may have beneficial effects but also may play a role in allergic sensitization (Milton, 1995; Peden & Boehlecke, 1999).

Studies of the health effects in humans and animals of inhaled endotoxin or lipopolysaccharides support a causal effect of endotoxin in acute airflow obstruction and airway inflammation. Repeated exposures to endotoxin can lead to the development of fever tolerance or endotoxin tolerance, which occurs approximately 24 h after exposure and lasts approximately 72 h (Rylander, 1994; Milton, 1996). This observation led to consideration of endotoxin as a possible cause of the Monday symptoms of cotton mill workers (Pernis et al, 1961). Endotoxin is accepted as a cause of humidifier fever (Milton, 1996).

Inhaled endotoxin causes a dose-related bronchoconstriction that develops 4–6 h following exposure and can increase airway reactivity, the latter being particularly pronounced in asthmatic persons (Rylander, 1994; Peden & Boehlecke, 1999). Low-level endotoxin exposures, only slightly in excess of outdoor background concentrations, have been reported in association with increased asthma severity and nonspecific building-related symptoms (Rylander et al, 1989; Michelet al, 1991; Gyntelberg et al, 1994; Teeuw et al, 1994). Michel et al (1991) found that endotoxin above 1.1 ng/mg in house dust was associated with increased asthma severity among adults.

Two large epidemiological studies have suggested that endotoxin may be related to nonspecific building-related symptoms (Milton, 1999). Teeuw et al (1994) studied airborne endotoxin in 19 Dutch government buildings and interviewed more than 1,300 office workers. The investigators reported higher airborne endotoxin concentrations in mechanically ventilated problem buildings than in mechanically or naturally ventilated nonproblem buildings. Gyntelberget al (1994) studied 12 buildings in Denmark and examined the association of symptoms with various parameters in carpet dust. There were no associations between symptoms and endotoxin concentrations, but fatigue, a sense of heavy-headedness, and throat irritation were strongly associated with the concentration of gram-negative bacteria.

Sample Collection and Analysis

Endotoxin exposure is measured primarily by collection of air samples on filters while bulk materials, water, and settled dusts are tested to identify potential endotoxin sources (AIHA, 1996d). Sampling for endotoxin is primarily a research activity due to problems with reagent standardization and data interpretation (Chun et al, 2000). However, sampling may be useful to confirm suspected exposures in agricultural and related industrial environments and where aerosols are generated from recirculated water and other materials contaminated with gram-negative bacteria (Milton, 1999).

Endotoxin potency is measured by the biological activity of a sample in a specified assay system, such as the Limulus amebocyte lysate (LAL) assay (AIHA, 1996d; Milton, 1995, 1999). The LAL assay is a comparative method that estimates the relative toxicity of a sample rather than an analytical method that would provide a quantitative measure of a physical substance (Milton, 1995). The bioavailability of endotoxin may vary depending on the nature of the material tested. Therefore, endotoxin concentrations as measured in the LAL assay may not predict accurately the toxic potential of a sample material in its natural setting (Boehlecke & Jacobs, 1994). When test conditions are not controlled strictly, nonspecific interferences with the LAL reaction may result in overestimation or underestimation of endotoxin content (Milton, 1995, 1999). The kinetic, chromogenic LAL assay combines accuracy, reproducibility, and sensitivity, and avoids sample-induced enhancement or inhibition (Olenchock, 1997; Milton, 1995, 1999).

Lipopolysaccharide (LPS) concentration can be measured by chemical methods, such as detection of 3-hydroxy fatty acids by gas chromatography–mass spectrometry (AIHA, 1996d), although chemical methods are not as sensitive as the LAL assay. Computation of the mass of lipopolysaccharides in a sample requires assumptions about the average molecular weight of the lipopolysaccharides (Milton, 1999). The number of moles of lipopolysaccharides in a sample can be estimated using the structural information that each lipopolysaccharide molecule contains four 3-hydroxy fatty acids (AIHA, 1996d).

Endotoxin Concentrations

Airborne endotoxin is found wherever organic dusts are present (for example, cotton mills, swine barns, and grain handling operations) and where recirculated industrial washwater or other contaminated materials are aerosolized (Olenchock, 1994; Milton et al, 1995; Jacobs, 1997; Milton, 1996, 1999). Results of the LAL assay are reported in Endotoxin Units (EU) with reference to the biological activity of a standard LPS preparation (1 EU = 0.1 ng of a reference standard endotoxin). Because of differences in methods for sample collection, extraction, and assay, it is not always possible to compare endotoxin measurements across studies (Milton, 1996). Outdoor concentrations of endotoxin may range up to ~3 EU/m^3 (0.3 ng/m^3) during the growing season due to aerosolization of gram-negative bacteria from leaves (Andrews & Hirano, 1992; Milton, 1999). Airborne endotoxin concentrations in homes and offices can be higher than those outdoors, for example, in the presence of contaminated humidifiers or after severe water damage (Milton, 1996). Rylander et al (1989) studied endotoxin and "α-(1,3)-*D*-glucan" in residences. Endotoxin was associated with fatigue and mucosal irritation when present above 0.2 ng/m^3; the maximum endotoxin concentration reported was 18 ng/m^3. Much higher airborne endotoxin concentrations have been measured in a variety of industrial work environments.

Recommended Relative Limit Values

Guidelines have been proposed for endotoxin exposure limits (Rylander, 1997). However, the imprecision of the LAL assay over time and among laboratories makes it impossible to establish a TLV® at a given endotoxin concentration. Therefore, ACGIH has proposed the use of relative limit values (RLVs) to evaluate endotoxin exposures (Milton, 1999). This approach is based on comparison of endotoxin levels in the environment in question with simultaneously determined background concentrations. Endotoxin levels between 10-fold and 100-fold higher than background frequently are associated with adverse health effects. Therefore, an employer may assume that endotoxin plays a role and should act to reduce exposures if workers experience health effects consistent with endotoxin exposure (for example, fatigue, malaise, cough, chest-tightness, and acute airflow obstruction) and endotoxin exposures exceed 10 times simultaneously determined, appropriate background concentrations. In environments with a potential for endotoxin exposure but no current health complaints, endotoxin concentrations should not exceed 30 times the appropriate background. If air concentrations exceed this level, employers should identify and control the source of gram-negative bacteria and reduce inhalation exposures to water mists and organic dust.

ORGANIC DUST TOXIC SYNDROME

Dusts of vegetable, animal, or microbial origin often are referred to as organic dusts. Workers are exposed to organic dust in a variety of environments including agricultural operations, industrial or manufacturing processes, and office and commercial settings. High exposures to organic dusts are common in occupations involving work with confined animals and the handling of grains or wood dusts. The composition of organic dust varies with the source material, but may contain fractured vegetable matter, arthropods, bacteria, fungi, and animal dander and proteins. *Organic dust toxic syndrome* (synonymous with grain fever, silo unloaders' disease, inhalation fever, toxic pneumonitis, and pulmonary mycotoxicosis) appears to result from inhaling particles and toxins produced by microorganisms. Bacterial contamination of organic dust is common. Therefore, endotoxin is a common component of organic dust and may be involved in organic dust toxic syndrome (Merchant, 1994; NIOSH, 1994; AIHL, 1996; Castranova et al, 1996). However, exposures in agricultural and other settings may be highly complex, and agents other than endotoxin may be important contributors to acute and chronic health effects associated with exposure to organic dust (Chan-Yeung et al, 1992; Malmberg & Larsson, 1993; Zhiping et al, 1996; Milton, 1999). Persons cleaning building materials extensively contaminated with fungi also may be at risk of developing organic dust toxic syndrome (NYCDOH, 2000), but the role of fungal toxins (mycotoxins) in organic dust toxic syndrome is unclear (Miller, 1994; Burge, 1999).

Organic dust toxic syndrome is a poorly characterized condition similar to humidifier fever and other acute inflammatory responses to heavy exposures to organic material. Yang and Johanning (1997) listed comparative clinical features of hypersensitivity pneumonitis and organic dust toxic syndrome. Organic dust toxic syndrome is diagnosed when short-lived, flu-like reactions follow within hours of exposures to high dust levels (ACGIH, 1999b). The diagnosis of organic dust toxic syndrome is based on a clinical presentation of fever, fatigue, and chills and lack of radiological, functional, immunological, or microbiological evidence of infectious disease or hypersensitivity pneumonitis (Chan-Yeung et al, 1992; do Pico, 1994). Unlike hypersensitivity pneumonitis, organic dust toxic syndrome is not an immune-mediated disease, does not require repeated exposures, and does not appear to cause permanent lung damage. No specific therapy is needed for organic dust toxic syndrome, which usually disappears within 24 h to a few days provided that the affected person is removed from exposure. Repeated episodes can occur after re-exposure to organic dusts, but no deaths have been attributed to organic dust toxic syndrome (NIOSH, 1994). Organic dust toxic syndrome is not widely recognized because only serious cases or clusters of cases attract medical attention and many physicians may fail to recognize this respiratory disease (NIOSH, 1994).

Organic dust toxic syndrome can be prevented through exposure control, health hazard education, and medical monitoring (Donham, 1994). Engineering controls can minimize the generation of dust and reduce air concentrations in many occupational settings. NIOSH has recommended respirators for workers exposed to organic dusts (NIOSH, 1994). Workers should be informed of the health effects of breathing organic dusts and the symptoms associated with organic dust toxic syndrome. Workers experiencing such symptoms should inform their physicians about recent dust exposure to avoid inappropriate treatment.

MYCOTOXINS

Fungi produce a variety of secondary metabolites (those not essential to the life of an organism) including mycotoxins and volatile organic compounds. Low-molecular-weight fungal products that have toxic effects on animals or humans are loosely termed fungal toxins or mycotoxins. The function of mycotoxins has not been clearly established, but they may play a role in regulating competition between fungi and other microorganisms and probably help parasitic fungi invade host tissues (Burge, 1999). The best known mycotoxins are aflatoxins, produced by certain strains of *Aspergillus flavus* and *Aspergillus parasiticus*; ochratoxins, produced by some species of *Penicillium* and *Aspergillus*; and thrichothecenes, produced by *Stachybotrys chartarum* (syn. *Stachybotrys atra*) and species of *Fusarium* (Hintikka & Nikulin, 1998).

The kinds and amounts of toxin a fungus produces depend on the fungal strain, the substrate it is metabolizing, growth conditions, and the presence of other organisms (Burge, 1999). Not all strains of potentially toxigenic fungi produce mycotoxins under laboratory conditions, even when grown on natural substrates (Rao et al, 1997; Jarvis et al, 1998). More than one fungal species or genus may produce the same mycotoxin. For example, *Aspergillus versicolor*, *Emericella nidulans*, and *Cochliobolus sativus* can make sterigmatocystin. Conversely, a single fungal species may produce more than one mycotoxin. For example, *S. chartarum* produces many toxic substances including satratoxin F, G, and H, roridin E, and verrucarin J (Burge, 1999).

Mycotoxins accumulate in fungal spores, mycelia, and growth substrates, and humans may be exposed to mycotoxins via ingestion of contaminated food, skin contact with contaminated materials, or inhalation of fungal spores and other material containing mycotoxins. These compounds are nonvolatile or have low volatility (Yang & Johanning, 1997). Therefore, significant exposure to mycotoxins as gases or vapors is unlikely. Spores are considered the most common vehicle for mycotoxin inhalation and can contain significant amounts of toxin (Miller, 1994; Hintikka & Nikulin, 1998; Burge, 1999).

Health Effects

In the past decade, concern regarding mycotoxin exposure in nonindustrial and nonagricultural indoor environments has

increased. Interest in mycotoxins arises from the potent health effects that have been elicited in laboratory animals, clear associations between respiratory disease and fungal exposure in agricultural settings, concern about military or terrorist use, and conclusions from case studies in residential and office buildings (Burge, 1999). Attention to the potentially fatal effects of mycotoxins on infants began with an investigation in Cleveland, Ohio. However, a review of that study concluded that a possible association between acute pulmonary hemorrhage/hemosiderosis in infants and exposure to fungi, specifically *Stachybotrys chartarum*, was not proven (CDC, 2000c).

Mycotoxins have a broad range of known and suspected health effects, including immune system, inflammatory, carcinogenic, cardiovascular, and neurologic effects (Miller, 1994; Yang & Johanning, 1997; Hintikka & Nikulin, 1998; Burge, 1999). Investigators have hypothesized that the occupants of buildings contaminated with potentially toxigenic fungi are suffering from mycotoxicosis when complaints of nasal stuffiness, sinus pain, sore throat, wheezing, bleeding from the nose or lung, eye irritation, and extreme fatigue cannot be attributed to allergies or infections (Ammann, 2000). Other complaints similar to nonspecific building-related symptoms that have implicated fungal toxins are increased susceptibility to infections, headache, memory and attention deficits, sleep disturbances, nausea, vomiting, and skin lesions and rashes.

Mycotoxicosis has been defined as an illness resulting from exposure to one or more toxic fungi and their products (Ammann, 2000) and as direct toxicity from exposure to fungal metabolites (Biagini, 2000). The effects of mycotoxins depend on the route of exposure (oral, dermal, or inhalation), the dose received, and the exposure pattern (acute or chronic). Effects attributed to mycotoxins in field settings have been observed at lower concentrations than were required to produce effects under controlled experimental conditions using spores of single fungi or isolated fungal toxins. This difference in responses may be due to a wider spectrum of susceptibility in the more heterogeneous field populations, differences in levels and durations of exposures, additive or synergistic actions of multiple toxins in the uncontrolled settings, actions of other toxic microbial compounds, responses to allergenic or irritant fungal agents, and the effects of simultaneous exposure to other contaminants (Ammann, 2000).

Biological markers of mycotoxin exposure (for example, the presence of an agent or a metabolite in blood or urine) have been sought and some serological markers have been proposed as evidence of exposure (Johanning et al, 1996, 1999; Burge, 1999; Dietrich et al, 2000). However, the reliability and significance of associations between potential indicators of inhalation exposure and various clinical signs and symptoms have not been established. The half-life for excretion of some mycotoxins is known to be on the order of hours to days with expected body burdens in the nanogram to picogram range, making traditional chemical analyses impractical or impossible (Biagini, 2000) and diagnosis after cessation of exposure difficult.

Environmental Sampling

Exposure to mycotoxin can be measured through collection of air and source samples. Samples are analyzed using chemical assays for specific mycotoxins or bioassays that demonstrate toxicity on selected cell lines or in whole animals (AIHA, 1996e; Hintikka & Nikulin, 1998; Hodgson et al, 1998; Jarvis et al, 1998; Burge, 1999; Dillon et al, 1999; Johanning et al, 1999). However, few laboratories have experience in these analyses for applications other than the testing of foods. Therefore, potential exposure to mycotoxins most often is inferred from identification of potentially toxigenic fungi (fungi known to produce mycotoxins) using culture methods or microscopic examination of collected material. Research is under way on the conditions required for fungal growth and mycotoxin production on building materials and on the efficacy of sanitation efforts (Rao et al, 1997; Price & Ahearn, 1999).

Precautions During Remediation of Fungal Contamination

Remediation of microbial contamination requires: (a) removal of porous materials that show extensive microbial growth, (b) physical removal of surface microbial growth on nonporous materials to typical background levels, and (c) reduction of moisture to levels that do not support microbial growth (Morey, 1999; Shaughnessy et al, 1999; Shaughnessy & Morey, 1999). Recommendations have been published advising levels of personal protection and containment for various degrees of biological contamination of building materials and furnishings. These recommendations focus on protecting workers from inhalation, skin, and mucous membrane exposure to potentially allergenic, inflammatory, or toxic bioaerosols. Control measures also are designed to ensure containment and safe removal of contaminated materials as well as minimization of dispersion of biological materials to uncontaminated areas. Some recommendations have been based on the types of microorganisms that have been identified as present (for example, fungi known to produce toxic substances, such as *A. flavus*, *Aspergillus fumigatus*, *A. versicolor*, *Fusarium moniliforme*, and *S. chartarum* and species of *Trichoderma* and *Memnoniella*) (Samson et al, 1994; Health Canada, 1995).

More recent documents recognize the limitations of environmental sampling methods to identify and quantify microbial contaminants, the lack of information on the toxin-producing potential of fungi not yet identified as toxigenic, and the likelihood that many fungi are hazardous because of their ability to elicit allergic reactions or to cause acute inflammatory disease in addition to toxic responses. For these reasons, the latter publications recommend similar precautions for remediation of all fungal contamination

(Burge, 1999; Shaughnessy & Morey, 1999; NYCDOH, 2000).

PFIESTERIA PISCICIDA

Organism

In the last decade a number of massive fish-kills have been observed in the mid-Atlantic estuarine waters. These events have been attributed to a presumptive toxin produced by *Pfiesteria piscicida*, a single-celled microorganism found in brackish waters. Under most conditions this protozoan-like dinoflagellate exists in a benign state. The organism generally lives on bacteria, algae, microfauna, and sloughed organic materials from fish prey. Twenty-four life stages have been identified, which include flagellate, amoeboid, and cyst stages (Burkholder & Glasgow, 1995). Most of these stages are nontoxic. Based upon observations, the optimum conditions for *Pfiesteria* toxin production that result in fish-kill include calm, shallow water with poor flushing; brackish conditions; warm temperatures; and abundant prey (fish) that produce the appropriate signal for toxin production.

Disease

Adverse health effects in humans have been described in connection with fish-kills and research associated with field and laboratory activities. These effects range from respiratory and eye irritation, skin rashes, gastroenteritis (stomach cramps, nausea, vomiting), to cognitive and personality changes (Glasgow et al, 1995). Persons at risk to *Pfiesteria* toxin exposure include commercial and recreational fishermen, divers, biologists working with *Pfiesteria*, and other persons whose activities involve contact with contaminated water during fish-kills.

Unlike human exposures to several other dinoflagellate-produced toxins (paralytic shellfish poisoning [saxitoxin] or ciguatera fish poisoning), where exposures are associated with eating fish or shellfish with high levels of accumulated toxin, *Pfiesteria* toxin exposure is not known to be associated with eating affected fish. Rather, illness is thought to be related to exposure to toxin-laden water either by direct skin contact or by inhalation of aerosolized contaminated water.

Prevention

The need to implement suitable containment conditions becomes important with the knowledge that aerosol exposure and skin contact with *Pfiesteria* toxin-contaminated water has caused instances of human illness. The difficult question is what guidelines to use, biological or chemical. *Pfiesteria piscicida* is not a human pathogen; it is the toxin that produces adverse health effects. The CDC/NIH *(BMBL)* guidelines specify four biosafety levels that are relevant for work with infectious microorganisms (CDC/NIH, 1999). Since the traditional biosafety levels do not apply in this situation, Appendix 1 in *BMBL* does give guidance for work with toxins of biological origin. Recently guidelines have been published that address handling chemicals in microbiology and biomedical laboratories (Hill et al, 1999). Four chemical safety levels (CSLs) are described that take into consideration the chemical hazard and the nature of the work with the chemical. Hill suggests that *Pfiesteria* toxin might be handled at CSL3 (substantial risk) rather than at BSL-2 or BSL-3. In addition to laboratory containment, field containment must also be addressed. State guidelines have been prepared for state employees in Maryland and North Carolina, both states that have had toxic *Pfiesteria* fish-kills (Maryland, 1998a & 1998b; North Carolina, 1998). These varied guidelines provide good insight into *Pfiesteria* toxin containment based upon the work activity, the level of contamination, and the work environment.

Much remains to be learned about *Pfiesteria piscicida*, its presumed toxin(s), the environmental conditions that promote toxin production, and the mechanisms by which the toxins produce adverse health effects in human beings. Long-term multistate cohort studies funded by the CDC are underway to collect baseline neurocognitive data and regular follow-up data on cohort members, and to study the linkage of neurocognitive findings with data on exposure to estuary water and the presence of *Pfiesteria* in these environments. The reader may wish to refer to other references on this subject (Burkholder, 1999; Oldach et al, 1999; Peterson, 2000).

REGULATIONS AND GUIDELINES

There are few specific regulations that target work environments where employees might be exposed to infectious microorganisms or other biological agents, except those for which Threshold Limit Values® have been established (for example, cellulose; some wood, cotton, and grain dusts; nicotine; pyrethrum; starch; subtilisins (proteolytic enzymes); sucrose; and vegetable oil mist) (ACGIH, 2000). See Appendix B, a reprint of the 2000 ACGIH *Threshold Limit Values and Biological Exposure Indices*®. The OSHA General Duty Clause (employers shall provide a workplace free of recognized hazards that cause or are likely to cause death or serious physical harm) is an example of an early, nonspecific regulation (OSHA, 1970). Various government agencies (such as NIH, the National Cancer Institute [NCI], and the CDC) published guidelines in the 1970s that addressed issues relevant to microbiological safety. Although guidelines do not have the same impact as regulations, they are considered the accepted standard of practice at the time of their publication. Activities conducted in a manner contrary to published guidelines are generally considered unacceptable. Unlike guidelines, regulations define detailed requirements for specific activities, with penalties for noncompliance.

The following lists highlight relevant agencies, regulations, guidelines, and standards applicable to manipulation, transport, and disposal of infectious microorganisms or materials and professional organizations where biosafety and infection control assistance can be obtained. See also Appendix A, Additional Resources, in this text.

Regulations That Affect Laboratory Biosafety Practices

- OSHA: 29 *CFR* 1910.1030: Occupational Exposure to Bloodborne Pathogens.
- OSHA: Occupational Health and Safety Act; General Duty Clause, Section 5(a)(1).
- OSHA: 29 *CFR* 1910.132-133: Personal Protective Equipment Including Eye and Face Protection.
- OSHA: 29 *CFR* 1910.134: Respiratory Protection, and 1910.139 for Respiratory Protection for M. tuberculosis.
- U.S. EPA: Genetically engineered organisms in industry and registration of disinfectants (TOSCA). Infectious wastes are not regulated by U.S. EPA. For information on EPA-registered disinfectants, see National Antimicrobial Information Network in Bibliography).
- U.S. DOT: 49 *CFR* Parts 106-107 and 171-180: Packaging and Transport of Hazardous Substances, Including Infectious Substances. (For further information contact the Office of Hazardous Materials 202-366-4488.)
- U.S.PHS: 42 *CFR* Part 72: Interstate Shipment of Etiologic Agent, July 1980; Update: CDC Notice of proposed rulemaking - Oct. 28, 1999 (CDC, 1999a).
- U.S.PHS: 42 *CFR* Part 71.54: Foreign Quarantine, Etiologic Agents, Hosts, and Vectors. (An application and information on importation permits may be obtained by calling 1-888-CDC-FAXX and when prompted entering document # 101000.
- U.S.PHS 42 *CFR* Part 72.6: Transfer of Select Biological Agents of Human Disease.
- U.S. Department of Commerce: Export of Infectious Agents of Humans, Animals, Plants and Related Materials. (For information contact DOC Bureau of Export Administration at 202-482-4811.)
- U.S. Postal Service: 39 *CFR* Part 111: Mailability of Etiologic Agents. Codified in the Domestic Mail Manual 124.38: Etiologic Agent Preparations. A copy can be obtained from the GPO.
- U.S. Department of Agriculture: For importation of infectious agents of livestock, poultry and other animal diseases, contact 301-734-3277. For importation of plant pests, contact 301-734-3277. Importation of both types of materials requires a permit.
- Clinical Laboratory Improvement Act (CLIA) PL 100-578, 1988. CDC published "Regulations for implementing the clinical laboratory improvement amendments of 1988: A summary," in *MMWR* 41:#RR-2, pp 1-17, 1992.
- Other: The FDA regulates antiseptics and disinfectants.

Guidelines for the Safe Use of Pathogenic or Oncogenic Microorganisms

- NIH: Guidelines for Research Involving Recombinant DNA Molecules. (Guidelines available on the NIH Office of Biotechnology Activities website.)
- USPHS / National Cancer Institute: Safety Standard for Research Involving Oncogenic Viruses. October 1974 (out of print).
- CDC/NIH: Biosafety in the microbiological and biomedical laboratory; U.S. safety standard for work involving infectious agents (CDC/NIH, 1999).
- NRC/NAS, National Research Council of the National Academy of Sciences: *Biosafety in the Laboratory—Prudent Practices for Handling and Disposal of Infectious Materials*.
- CDC: *Infection Control Guidelines*. (Hospital Infections Branch.)

Standard-Setting or Credentialing Groups

- JCAHO, Joint Commission on Accreditation of Healthcare Organizations (Certification of laboratories in health care organizations), Oakbrook Terrace, Ill.
- NSF, National Sanitation Foundation (Standard #49—Class II laminar flow biohazard cabinetry; Ann Arbor, Mich.)
- NCCLS, National Committee for Clinical Laboratory Standards, Villanova, Pa. Guidelines for: the protection of laboratory workers from instrument biohazards and infectious disease transmitted by blood, body fluids and tissue; and the handling and transport of clinical specimens.
- ASTM, American Society for Testing and Materials, Philadelphia, Pa.

Professional Associations

- American Biological Safety Association, Mundelein, Ill.
- American Society for Microbiology, Public and Scientific Affairs Board, Laboratory Practices Committee, Laboratory Safety Subcommittee, ASM, Washington DC
- American Industrial Hygiene Association, Biosafety Committee, Fairfax, Va.
- American Conference of Governmental Industrial Hygienists. Committees on: Agricultural Health and Safety; Air Sampling Instruments; Bioaerosols; Construction; and Infectious Agents. Cincinnati, Ohio
- Association of Professionals in Infection Control, Washington DC
- American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, Ga.
- Campus Safety Association (associated with the National Safety Council)
- National Safety Council, Itasca, Ill.
- Society for Healthcare Epidemiologists of America, Woodbury, NJ

ROLE OF INDUSTRIAL HYGIENISTS AND ENVIRONMENTAL HEALTH AND SAFETY PROFESSIONALS IN BIOSAFETY

Industrial hygienists and environmental health and safety professionals are trained to identify workplace and environmental

hazards, evaluate their significance, and recommend programs and controls to eliminate or minimize occupational exposures. In addition to focusing on chemical and physical hazards, industrial hygienists and environmental health and safety professionals are often required to evaluate work-related illness caused by biological agents. Evaluation of illness or exposure in environments associated with agricultural work, mining, textile manufacturing, water systems, and sewage treatment, to list a few, have routinely been undertaken by industrial hygienists and environmental health safety professionals.

Depending on technical background and interest, the work activities of some industrial hygienists and environmental health safety professionals cover the broad range of biohazardous materials described in this chapter. However, the majority, because they lack training in pathogenic microbiology, infection control, and medical epidemiology, narrow the range of their biosafety activities. Under these circumstances, biosafety activities may only include agents such as *Legionella*, fungi, and other biological agents involved in indoor air quality, including potential allergens or toxins from bacteria (endotoxins), fungi (mycotoxins), and plant pollens.

Industrial hygienists and environmental health safety professionals can play an important role in the development and implementation of a biosafety program. Their training and experience enable them to understand and monitor biological activities in relatively low-risk biohazard situations (BSL-1 or -2). When work involves handling more hazardous agents requiring BSL-3 containment, such as *M. tuberculosis*, and the industrial hygienist or environmental health and safety professional is not an experienced microbiologist, then assistance should be obtained from a biological safety professional. This is similar to the role of the industrial hygienist in radiation safety, who requires the assistance of a professional in health physics in certain high-risk situations. The names of registered biosafety professionals may be obtained from the American Biological Safety Association (ABSA) in Mundelein, Illinois. Presently, the pool of certified biosafety specialists is relatively small. Fortunately, both professions have successfully used each other's expertise to resolve issues related to occupational exposure to biological agents.

SUMMARY

Agricultural, medical, and laboratory workers are most at risk to occupational biohazards, but many workplaces have the potential for such exposure, for example, microbiology, public health, and molecular biology laboratories; hospitals and other health care institutions; biotechnology facilities; veterinary practices; farms; wood-processing facilities; mines; textile manufacturing; and fishing and forestry industries. Therefore, containment of microorganisms and other biological hazards in all workplaces is critical to the health of workers and to the community. Engineering controls—safety equipment and facility design—and worker-initiated workplace controls—good work practices and carefully executed techniques—can minimize occupational biohazardous exposures.

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ADDENDUM: LARGE-SCALE GUIDELINES

Biosafety guidelines for work with small volumes of infectious agents, i.e., those amounts typically used for diagnosis, characterization, or basic research, have been established by CDC and NIH (1999), the WHO (1993), the United Kingdom (Advisory Committee on Dangerous Pathogens, 1995), and Canada (LCDC, 1996). Guidelines for working with recombinant DNA molecules in large volumes exist in the NIH Guidelines for Research with Recombinant DNA Molecules (NIH, 1999). Several other publications have dealt with large scale requirements and guidelines in the United States (Fleming, 1995, pp 203–217; Fleming, 1996). The United Kingdom has put together additional guidance for large-scale work (Advisory Committee on Dangerous Pathogens, 1998). The following document is an attempt to put together a comprehensive biosafety guideline for dealing with various types of large-scale work with microorganisms. The pertinent features of the existing documents have been put together with specific recommendations for large-scale work and are included in this version.

It is understood that the organism, quantity, and process have a significant impact on the choice of an appropriate biosafety level for the work to be conducted. There is no specific volume that constitutes "large scale" for microbial agents. Certain CDC-NIH guidance documents have referred to large scale as volumes typically in excess of those used for identification, typing, assay performance or testing. The risk analysis must include an assessment of the infectivity of the agent, the routes of transmission, the severity of infection, the availability of prophylaxis, the level of containment afforded by the process and equipment used, etc., not just the volume of material being handled. Similarly, there is little scientific evidence to support the premise that only volumes greater than 10 liters merit large scale requirements. Certainly, that is not true for BSL-2 and BSL-3 organisms. The CDC/NIH (1999) guidelines recommend raising the biosafety level for culturing and purification of many BSL-2 organisms, however, that was only done in an effort to provide considerations for the biosafety officer and scientists in the establishment of the appropriate level of protection. The NIH recombinant DNA guidelines provide guidance for the large scale use of recombinant organisms to protect the environment, but do not adequately address the level of containment necessary to protect the personnel working with infectious agents.

This document serves as an effort to collect best practices for maximizing the safety for large scale work, and can be utilized by an Institutional Biosafety Committee and/or a Biological Safety Officer to develop biosafety procedures for the work to be done.

The guidelines will cover four different levels for large scale work: Good Large Scale Practices (GLSP), Biosafety Level 1-Large Scale (BSL1-LS), Biosafety Level 2-Large Scale (BSL2-LS), and Biosafety Level 3-Large Scale (BSL3-LS). The containment conditions for Biosafety Level 4-Large Scale are not defined here, but should be determined on a case by case basis.

Only the biological hazard of the organism is addressed here. Other hazards, such as the toxicity or biological activity of the products produced, should be considered separately. These guidelines do not specifically address animal or plant pathogens, however, the containment principles and practices may be useful for some of those agents.

All institutions that engage in large scale research or production with microorganisms should appoint a Biological Safety Officer (BSO) to oversee the procedures, facilities and equipment used. A BSO is critical at BSL2-LS and above, where knowledge and experience with handling pathogenic organisms, biosafety practices, and containment design criteria are required.

Good Large-Scale Practices

The Good Large-Scale Practices (GLSP) level is recommended for certain Risk Group 1 organisms that are not known to cause disease in healthy adults, are non-toxigenic, are well characterized and/or have an extended history of safe large scale work. These organisms should not be able to transfer antibiotic resistance to other organisms. Examples of these organisms include *Saccharomyces cerivisiae*, *E. coli K12*, etc. These organisms should have limited survival and/or no adverse consequences if released into the environment.

STANDARD MICROBIOLOGICAL PRACTICES

1. Individuals wash their hands after handling viable material. Antiseptic hand cleanser may be used as an interim measure if a sink is not readily accessible.
2. Eating, drinking, smoking, handling contact lenses, and applying cosmetics are not allowed in the work area.
3. Mouth pipetting is prohibited.
4. Work surfaces are capable of being cleaned and disinfected.
5. An insect and rodent control program is in effect.

SPECIAL PRACTICES

1. Institutions that engage in large scale work should have a health and safety program for their employees.
2. Written instructions and training are provided for personnel who work at GLSP conditions.
3. Processing, sampling, transfer, handling, etc., of viable organisms is done in a manner that does not adversely affect the health and safety of the employees.
4. Discharges of viable organisms are disposed of in accordance with applicable local, state, and federal requirements.
5. The facility should have an emergency response plan that includes the handling of spills.

SAFETY EQUIPMENT

1. Protective clothing, e.g., uniforms, laboratory coats, etc., is provided to minimize the soiling of personal clothing.
2. Safety glasses are worn in the facility.

FACILITIES

Each facility contains a sink for hand washing or has an antiseptic waterless hand cleanser available. If present, the sink should be located near the exit doorway. An eyewash station and emergency shower are provided in the work area or easily accessible to it.

Biosafety Level 1 - Large-Scale (BSL1-LS)

BSL1-LS is recommended for the large scale growth of Risk Group 1 organisms that are not known to consistently cause disease in healthy adult humans and pose minimal hazard to personnel and the environment, but otherwise do not qualify for GLSP level.

STANDARD MICROBIOLOGICAL PRACTICES

1. Access to the work area may be restricted at the discretion of the project manager when work is ongoing. A warning sign should be placed on the door that lists the agent(s) being used, the names and telephone number of persons knowledgeable about and responsible for the facility, and entry requirements, if any.
2. Persons wash/clean their hands after they handle viable organisms, after removing gloves, and on leaving the work area. Antiseptic hand cleanser may be used as an interim measure if a sink is not readily accessible.
3. Eating, drinking, smoking, handling contact lenses, and applying cosmetics are not permitted in the work area.
4. Food is stored outside of the work area in cabinets or refrigerators designated and used for this purpose only.
5. Mouth pipetting is prohibited. Only mechanical pipetting devices are used.
6. Work surfaces are decontaminated on a routine basis and after any spill of viable organisms.
7. Procedures are performed carefully in a manner that minimizes aerosol generation.
8. Policies for the safe handling of sharps are instituted. The use of sharps should be minimized.
9. All discharges of the viable organisms are disposed of in accordance with applicable local, state and federal regulations.
10. An insect and rodent control program is in effect.

SPECIAL PRACTICES

1. Institutions that engage in large-scale work have a health and safety program for their employees.
2. Written procedures and training in basic microbiological practices are provided and documented.
3. Medical evaluation, surveillance and treatment are provided where indicated; e.g., determine functional status or competency of employees' immune system when working with opportunistic pathogens, etc.
4. Spills and accidents, which result in overt exposure to viable organisms, are reported to the facility supervisor/manager. Medical evaluation, surveillance, and treatment are provided as appropriate and written records are maintained.
5. Emergency plans shall include methods and procedures for handling spills and employee exposures.
6. Cultures of viable organisms are handled in a closed system or other primary containment equipment, which is designed to reduce the potential for the escape of viable organisms.
7. Sample collection and material addition to a closed system, and transfer of culture materials from one closed system to another are conducted in a manner that minimizes employee exposure, the release of viable material and the generation of aerosols.
8. Cultures of viable organisms should be inactivated by a validated process prior to removal from the closed system or primary containment system, except as allowed in # 7, or where the viable organism or viral vector is the desired product. In the latter case, the viable organisms should be removed from the closed system or other primary containment system in a manner that minimizes employee exposure, the release of viable material and the generation of aerosols.
9. Exhaust gases removed from a closed system or other primary containment system minimize the release of viable organisms to the environment by the use of appropriate filters or procedures.
10. A closed system or other primary containment equipment that has contained viable organisms shall not be opened for maintenance or other purposes until it has been decontaminated.

SAFETY EQUIPMENT

1. Protective clothing, e.g., uniforms, laboratory coats, etc., is provided to prevent the contamination or soiling of personal clothing.
2. Safety glasses must be worn.
3. Gloves are worn if the skin on the hands is broken, irritated, or otherwise not intact.

FACILITIES

1. Each facility contains a sink for hand washing or has an antiseptic waterless hand cleanser available. If present, the sink should be located near the exit doorway. An eyewash station and emergency shower should be provided in the work area or easily accessible to it.
2. The work area has a door that can be closed when large scale work is ongoing.
3. The work area is designed to be easily cleaned.
4. Floors can be cleaned and disinfected in case of spills of viable organisms. Rugs are not allowed.
5. Work surfaces are impervious to water and resistant to acids, alkali, organic solvents, disinfectants and moderate heat.
6. Furniture in the work area is sturdy and placed so that all areas are accessible for cleaning.
7. If the work area has windows that open, they are fitted with fly screens.
8. Facilities are designed to contain large spills of viable materials within the facility until appropriately decontaminated.

This can be accomplished by utilizing a dike, or sloping or lowering the floor where the process vessels are located. The design should minimize the release of viable organisms directly to the sewer.

Biosafety Level 2 - Large-Scale (BSL2-LS)

BSL2-LS is recommended for the propagation and cultivation of Risk Group 2 infectious organisms, and other organisms, such as attenuated strains from a higher Risk Group, that would be handled at BSL-2 in laboratory scale. The following guidelines have been developed for facilities that handle large volumes of these materials.

STANDARD MICROBIOLOGICAL PRACTICES

1. Access to the work area is restricted to personnel who meet the entry requirements.
2. Persons wash their hands after they handle viable organisms, after removing gloves and before leaving the work area.
3. Eating, drinking, smoking, handling contact lenses, and applying cosmetics are not permitted in the facility.
4. Food is stored outside of the facility in cabinets or refrigerators designated and used for this purpose only.
5. Mouth pipetting is prohibited. Only mechanical pipetting devices are used.
6. Work surfaces are decontaminated on a routine basis and after any spill of viable organisms.
7. Procedures are performed carefully in a manner that prevents aerosol generation.
8. All contaminated wastes are decontaminated by an approved method prior to disposal in accordance with local, state, and federal regulations. Wastes that need to be transported to a different area or facility are closed and placed in a durable, leakproof container for transfer. Material to be transferred off site for decontamination is packaged and labeled in accordance with the applicable regulations.
9. All discharges of viable organisms are inactivated by a validated process, i.e., one that has been demonstrated to be effective using the organism in question, or with an indicator organism that is known to be more resistant to the physical or chemical methods used; e.g., *Bacillus stearothermophilus* for steam heat.
10. An insect and rodent control program is in effect.

SPECIAL PRACTICES

1. Institutions that engage in large scale work have a health and safety program for their employees.
2. Doors to the work area are kept closed when work is ongoing.
3. Access to the work area is restricted to personnel whose presence is required and who meet entry requirements, i.e., immunization, if any. Individuals who cannot take or do not respond to the vaccine, who cannot take the recommended prophylaxis in the event of an exposure incident, who are at increased risk of infection, or for whom infection may prove unusually hazardous, are not allowed in the work area until their situation has been reviewed by appropriate medical personnel. The individuals are informed of the potential risks and sign an acknowledgment, consent form, or similar vehicle, which indicates that they understand and accept the potential risk.
4. Written procedures and policies for handling infectious organisms are provided.
5. Personnel are able to demonstrate proficiency in standard microbiological practices and procedures, and the handling of human pathogens at a Biosafety Level 2. This can consist of previous experience and/or training. Training in the hazards associated with the organisms involved, and the practices and operations specific to the large scale work area are provided and documented.
6. Appropriate immunizations, medical evaluation surveillance, and treatment are provided where indicated; i.e., immunization, survey of immune status, etc.
7. A hazard warning sign, incorporating the universal biohazard symbol, identifying the infectious agents, listing the name and telephone numbers of the persons knowledgeable about and responsible for the work area, along with any special entry requirements for entering the work area, is posted at the entry to the work area.
8. When appropriate, baseline serum samples or other surveillance samples are collected and stored for all personnel working in or supporting the work area.
9. A biosafety manual is available which details required safety practices and procedures, spill cleanup, handling of accidents, and other appropriate safety information.
10. The use of sharps is avoided. If required, additional safety devices or personal protective equipment are used to prevent accidental exposure. Plastic laboratory ware is substituted for glassware whenever possible. If glassware is used, it is coated or shielded to minimize the potential for breakage.
11. Viable organisms are placed in a container that prevents leakage during collection, handling, processing, and transport.
12. Viable organisms are handled in a closed system or other primary containment equipment that prevents their release into the environment.
13. Sample collection, material addition to a closed system, and transfers of culture materials from one closed system to another, are conducted in a manner that prevents employee exposure and the release of viable material from the closed system.
14. Culture fluids are not removed from a closed system (except as allowed in #13) unless the viable organisms have been inactivated by a validated procedure. In cases where the viable organism/viral vector is the desired product, the materials should be removed and processed in equipment that prevents employee exposure and release of viable material.

15. Exhaust gases removed from a closed system or other primary containment systems are filtered or otherwise treated to prevent the release of viable organisms to the environment.
16. A closed system that has contained viable organisms will not be opened for maintenance or other purposes unless it has been decontaminated.
17. Rotating seals and other mechanical devices directly associated with a closed system used for the propagation of viable organisms are designed to prevent leakage or are fully enclosed in ventilated housings that are exhausted through filters or otherwise treated to prevent the release of viable organisms to the environment
18. Closed systems, used for the propagation of viable organisms and other primary containment equipment, are tested for the integrity of the containment features prior to use, and following any changes/modifications to the system that could affect the containment characteristics of the equipment. These systems are equipped with a sensing device that monitors the integrity of the containment while in use. Containment equipment, for which the integrity cannot be verified or monitored during use, is enclosed in ventilated housings that are exhausted through filters or otherwise treated to prevent the release of viable organisms.
19. Closed systems that are used for propagation of viable organisms or other primary containment equipment are permanently identified. This identifier is used on all records regarding validation, testing, operation, and maintenance.
20. Contaminated equipment and work surfaces are decontaminated with a suitable disinfectant on a routine basis, after spill cleanup, etc. Contaminated equipment is decontaminated prior to servicing or transport. Absorbent toweling/coverings used on work surfaces to collect droplets and minimize aerosols are discarded and decontaminated after use.
21. Individuals seek medical attention immediately after an exposure incident. Spills and accidents that result in overt exposure to infectious materials are immediately reported to the facility supervisor/manager and the BSO. Appropriate medical treatment, medical evaluation, and surveillance are provided, and written records maintained.
22. Emergency procedures include provisions for decontamination and cleanup of all spills/releases of viable material, including proper use of personal protective equipment.
23. Animals not involved in the work being performed, are not permitted in the work area.

SAFETY EQUIPMENT

1. Protective clothing, e.g., lab coats, protective coveralls, etc., is worn to prevent contamination of personal clothing. If the organism can be transmitted through the skin, the protective clothing should be waterproof with a solid-front, wraparound, or back- or side-tie coats. Protective clothing is removed when leaving the work area.
2. Protective eye wear is worn at all times in the work area. Protective face protection, i.e., face shield or goggles and face mask/respirator are worn for any procedures that may involve splashing or spraying. Respirators are worn if the agents involved are transmissible via the respiratory route.
3. Impervious gloves are worn at all times in the work area when work is ongoing. Double gloving is considered if personnel are working for extended periods of time, or with processes that may require direct contact with the infectious material. Gloves are discarded upon leaving the work area.
4. The selection of a respirator/face mask is made based on the transmissibility of the agent. If the agent is transmitted through the respiratory route, a respirator with a filtration efficiency capable of protecting the individual from the organism is used, e.g., HEPA for viruses, N95s for *M. tuberculosis*, etc. If the agent is transmitted through mucous membrane contact, a face mask that prevents droplet penetration, e.g., plastic molded, is preferred. Personnel are trained in the use of respirators/face masks for procedures that may involve aerosol generation, and for emergency situations that involve the release of viable organisms in the work area.
5. Biological safety cabinets or other ventilated containment devices can be used to contain aerosol-generating processes or to prevent contamination of viable organisms when removed from a closed system.
6. Only centrifuge units with sealed rotor heads or safety cups that can be opened in a biological safety cabinet are used; or the centrifuge is placed in a containment device.

FACILITIES

1. Each facility contains a sink for hand washing, an eyewash station, and an emergency shower. The sink is foot, elbow, automatic, etc., or otherwise not hand-operated, and located near the door of each room in the work area.
2. The work area has a door that is closed when large scale work is ongoing.
3. The work area is designed to be easily cleaned and disinfected. Furniture and stationary equipment are sealed to the floor or raised to allow for cleaning and disinfection of the facility.
4. Floors, walls, and ceilings are made of materials that allow for cleaning and disinfection of all surfaces. Light fixtures are covered with a cleanable surface.
5. Work surfaces are impervious to water and resistant to acids, alkali, organic solvents, disinfectants and moderate heat.
6. Windows to the facility are kept closed and sealed while work is ongoing.
7. General laboratory-type work areas are designed to have a minimum of 6 air changes per hour. For large scale facilities the number of air changes per hour will depend on: the size of the area, the chemicals and agents handled, the procedures and equipment utilized, and the microbial/particulate requirements for the area.

8. The ventilation in the work area is designed to maximize the air exchange in the area, i.e., the supply and exhaust are placed at opposite ends of the room, ceiling supply with low level exhaust, etc.
9. The work areas in the facility where the infectious organisms are handled are at negative pressure to the surrounding areas.
10. Provisions are made to contain large spills of viable organisms within the facility until appropriately decontaminated. This can be accomplished by placing the equipment in a diked area, or sloping or lowering the floors in those areas to allow for sufficient capacity to contain the viable material and disinfectant.
11. Drainage from the facility is designed to prevent the release of large volumes of viable material directly to sewer, e.g., floor drains are capped, raised, or fitted with liquid tight gaskets to prevent release of untreated organisms to sewer.

Biosafety Level 3 - Large-Scale (BSL3-LS)

BSL3-LS is recommended for the propagation and cultivation of infectious organisms classified as Risk Group 3, which are handled at BSL 3 at Laboratory Scale. The following guidelines have been developed for facilities that handle large volumes of these materials.

STANDARD MICROBIOLOGICAL PRACTICES

1. Access to the facility is restricted to personnel who meet the entry requirements. Individuals who have not been trained in the operating and emergency procedures of the facility, are accompanied by trained personnel at all times while in the facility.
2. Persons wash their hands after they handle viable materials, after removing gloves and before leaving the work area.
3. Eating, drinking, smoking, handling contact lenses, and applying cosmetics are not permitted in the work area.
4. Food is stored outside of the work area in cabinets or refrigerators designated and used for this purpose only.
5. Mouth pipetting is prohibited. Only mechanical pipetting devices are used.
6. Work surfaces are decontaminated on a routine basis and after any spill of viable material.
7. Procedures are performed carefully in a manner that prevents aerosol generation.
8. All contaminated wastes are decontaminated by an approved method prior to disposal in accordance with local, state, and federal regulations. Wastes that need to be transported to a different area or facility, are closed and placed in a durable, leakproof container for transfer. Material to be transferred off site for decontamination is packaged and labeled in accordance with the applicable regulations.
9. All discharges of the viable materials are inactivated by a validated process, i.e., one that has been demonstrated to be effective using the organism in question, or with an indicator organism that is known to be more resistant to the physical or chemical methods used; e.g., *Bacillus stearothermophilus* for steam heat.
10. An insect and rodent control program is in effect.

SPECIAL PRACTICES

1. Institutions that engage in large scale work must have a health and safety program for their employees.
2. Doors to the facility are kept closed except for entry and egress.
3. Access to the facility is restricted to personnel whose presence is required and who meet entry requirements, i.e., immunization, if any, and comply with all entry and exit procedures. Individuals who cannot take or do not respond to the vaccine, who cannot take the recommended prophylaxis in the event of an exposure incident, who are at increased risk of infection, or for whom infection may prove unusually hazardous, are not allowed in the work area until their situation has been reviewed by appropriate medical personnel. The individuals are informed of the potential risks and sign an acknowledgment, consent form, or similar vehicle, which indicates that they understand and accept the potential risk.
4. Written procedures and policies for handling infectious materials are provided.
5. All personnel working at a BSL3-LS must demonstrate proficiency in standard microbiological practices and techniques, and in handling human pathogens at a Biosafety Level 3. This can consist of previous experience and/or training program. Training in the hazards associated with the materials involved, and the practices and operations specific to the facility are provided and documented.
6. Appropriate immunizations, medical evaluation surveillance, and treatment are provided where indicated; e.g., immunization, survey of immune status, etc.
7. A hazard warning sign, incorporating the universal biohazard symbol, identifying the infectious agents, listing the name and telephone numbers of the persons knowledgeable about and responsible for the facility, along with any special entry requirements for entering the work area, is posted at the entry to the facility.
8. Baseline serum samples or other appropriate specimens are collected and stored for all personnel working in or supporting the facility. Additional specimens may be collected periodically depending on the agents handled.
9. A biosafety manual is available which details required safety practices and procedures, spill cleanup, handling of accidents, and other appropriate safety information.
10. The use of sharps is avoided. If required, additional safety devices or personal protective equipment is used to prevent accidental exposure. Plastic laboratory ware is substituted for glassware whenever possible. If glassware is used, it is coated or shielded to minimize the potential for breakage.

11. Viable organisms are placed in a container that prevents leakage during collection, handling, processing, and transport.
12. Viable organisms are handled in a closed system or other primary containment equipment which prevents their release into the environment.
13. Sample collection and material addition to a closed system, and transfer of culture materials from one closed system to another is conducted in a manner that prevents employee exposure and the release of viable material from the closed system.
14. Culture fluids are not removed from a closed system (except as allowed in #14) unless the viable organisms have been inactivated by a validated procedure. In cases where the viable organism/viral vector is the desired product, the materials should be removed and processed in equipment that prevents employee exposure and release of viable material.
15. Exhaust gases removed from a closed system or other primary containment systems are filtered or otherwise treated to prevent the release of viable organisms to the environment.
16. A closed system that has contained viable organisms will not be opened for maintenance or other purposes unless it has been decontaminated.
17. Rotating seals and other mechanical devices directly associated with a closed system used for the propagation of viable organisms are designed to prevent leakage or are fully enclosed in ventilated housings that are exhausted through filters or otherwise treated to prevent the release of viable organisms.
18. Closed systems, used for the propagation of viable organisms and other primary containment equipment, are tested for the integrity of the containment features prior to use, and following any changes/modifications to the system that could affect the containment characteristics of the equipment. These systems are equipped with a sensing device that monitors the integrity of the containment while in use. Containment equipment for which the integrity cannot be verified or monitored during use, is enclosed in ventilated housings that are exhausted through filters or otherwise treated to prevent the release of viable organisms.
19. Closed systems that are used for propagation of viable organisms or other primary containment equipment are permanently identified. This identifier is used on all records regarding validation, testing, operation, and maintenance.
20. Contaminated equipment and work surfaces are decontaminated with a suitable disinfectant on a routine basis, after spill cleanup, etc. Contaminated equipment is decontaminated prior to servicing or transport. Absorbent toweling/coverings used on work surfaces to collect droplets and minimize aerosols should be discarded and decontaminated after use.
21. Individuals seek medical attention immediately after an exposure incident. Spills and accidents that result in overt exposure to infectious materials are immediately reported to the facility supervisor/manager and the BSO. Appropriate medical treatment, medical evaluation, and surveillance are provided, and written records maintained.
22. Emergency procedures include provisions for decontamination and cleanup of all spills/releases of viable material, including proper use of personal protective equipment.
23. Animals not involved in the work being performed, are not permitted in the work area.

SAFETY EQUIPMENT

1. Persons entering the facility will exchange or completely cover their clothing with garments such as solid-front or wrap-around gowns, coveralls, etc. If the organism can be transmitted through the skin, the protective clothing must be waterproof. Head and shoe covers, or dedicated shoes are provided. Protective clothing is to be removed when leaving the facility and decontaminated before disposal or laundering.
2. Protective eye wear is worn at all times in the work area. Protective face protection, i.e., face shield or goggles and face mask/respirator are worn for any procedures that may involve splashing or spraying. Respirators are worn if the agents involved are aerosol transmissible.
3. Impervious gloves are worn at all times in the work area when work is ongoing. Double gloving is considered if personnel are working for extended periods of time, or with processes that may require direct contact with the infectious material. Gloves are discarded upon leaving the work area.
4. The selection of a respirator/face mask is made based on the transmissibility of the agent. If the agent is transmitted through the respiratory route, a respirator with a filtration efficiency capable of protecting the individual from the organism is used, e.g., HEPA for viruses, N95s for *M. tuberculosis*, etc. If the agent is transmitted through mucous membrane contact, a face mask which prevents droplet penetration, e.g., plastic molded, is preferred. Personnel are trained in the use of respirators/face masks for procedures that may involve aerosol generation, and for emergency situations that involve the release of viable organisms in the work area.
5. Class II or III Biological safety cabinets or other ventilated containment devices are used to contain processes of viable materials if removed from a closed system.
6. Only centrifuge units with sealed rotor heads or safety cups that can be opened in a biological safety cabinet are used; or the centrifuge is placed in a containment device.
7. Continuous flow centrifuges or other aerosol generating equipment are contained in devices that are exhausted through filters or otherwise treated to prevent the release of viable organisms.
8. Vacuum lines are protected with liquid disinfection traps and HEPA filters or equivalent, which are routinely maintained and replaced as needed.

FACILITIES

1. The facility is separated from areas that are open to unrestricted traffic flow within the building. The entry area to the facility consists of a double-doored entry area, such as an airlock or pass-through.
2. Each major work area contains a sink for hand washing, which is not hand-operated, e.g., automatic, foot-, or elbow-operated.
3. An eyewash station and emergency shower is available in the facility.
4. The facility is designed to be easily cleaned and disinfected. Furniture and stationary equipment are sealed to the floor, raised, or placed on wheels to allow for cleaning and disinfecting of the facility.
5. Work surfaces are impervious to water and resistant to acids, alkali, organic solvents, disinfectants and moderate heat.
6. Floors, walls, and ceilings are made of materials that allow for cleaning and disinfection of all surfaces. Light fixtures are sealed, or recessed and covered with a cleanable surface.
7. Penetrations into the containment facility are kept to a minimum and sealed to maintain the integrity of the facility.
8. Windows to the facility are kept closed and sealed.
9. Liquid and gas services to the facility are protected from backflow unless they are dedicated to the facility. Fire protection sprinkler systems do not require backflow prevention devices.
10. The ventilation system for the facility is designed to control air movement;
11. The position of the supply and exhaust vents is designed to maximize the air exchange in the area, i.e., the supply and exhaust are placed at opposite ends of the room, ceiling supply with low level exhaust, etc.
12. General laboratory-type work areas are designed to have a minimum of 6 air changes per hour. For large scale facilities, the number of air changes per hour will depend on: the size of the area, the chemicals and agents handled, the procedures and equipment utilized, and the microbial/particulate requirements for the area.
13. The facility is at negative air pressure to the surrounding areas or corridors. The system shall create directional airflow that draws air from the "clean" areas of the facility into the "contaminated" areas. If there are multiple contaminated areas, the area of highest potential contamination is the most negative.
14. The exhaust air from the facility is not recirculated to any other area in the facility, and is discharged to the outside through HEPA filters or other treatments that prevent the release of viable microorganisms.
15. The facility has a dedicated air supply system for the facility. If the supply system is not dedicated to the facility, it contains HEPA filters or appropriate dampers, which can protect the system from potential backflow in the event of a system failure.
16. The supply and exhaust systems for the facility are interlocked to prevent the room from being pressurized in the event of power or equipment failure. The system is alarmed to indicate system failures or changes in desired air flow.
17. A visual monitoring device that indicates and confirms directional airflow is provided at the entry to the facility.
18. Visual/audible alarms should be available to notify personnel of any HVAC system failure.
19. A method for decontaminating all wastes is available in the facility, i.e., autoclave, chemical disinfection, incineration, or other approved method.
20. Provisions are made to contain large spills of viable organisms within the facility until appropriately decontaminated. This can be accomplished by placing the equipment in a diked area, or sloping or lowering the floors in those areas to allow for sufficient capacity to contain the viable organisms and disinfectant.
21. Drainage from the facility is designed to prevent the release of viable organisms directly to sewer, e.g., floor drains are capped, raised, or fitted with liquid tight gaskets to prevent release of untreated organisms to sewer.

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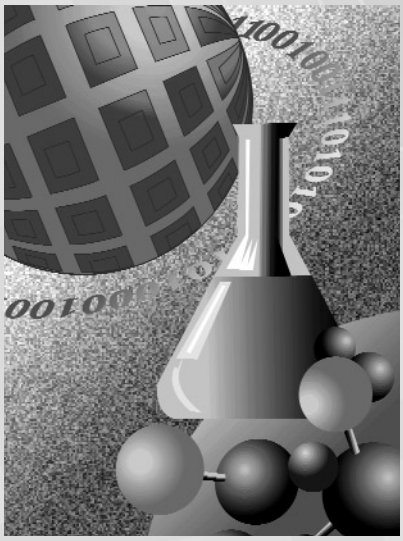

Evaluation of Hazards

Part IV

Chapter 15

Evaluation

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In industrial hygiene, evaluation is the decision-making process that assesses the hazard to workers from exposure to chemical, physical, and biological agents. The actions taken to protect workers are based on a combination of observation, interviews, and measurement of both the levels of energy or air contaminants arising from a process or work operation and the effectiveness of control measures used.

GENERAL PRINCIPLES

The need to evaluate hazards is driven by the acknowledgment that chemical, biological, and physical agents can cause injury, disease, and premature death among exposed workers. The U.S. Department of Labor's Bureau of Statistics reported 6.2 million occupational work-related injuries and illnesses in private industry in 1997. The actual number is much larger, because many occupational illnesses are unrecognized, many injuries and illnesses are not reported, and the public sector is not included in this count. For example, Leigh et al used multiple data sources to estimate the societal burden of occupational injury and illness: 6,500 job-related deaths from injury, 13.2 million nonfatal injuries, 60,300 deaths from disease, and 862,200 illnesses each year. The task of evaluating the nature and severity of hazards and prevention of disease and death relies on judgment based on many factors:

- *Toxicity:* the inherent capacity of an agent to cause harm, the nature of that harm, and target organs affected.
- *Exposure levels*, or *dose:* the amount that workers absorb through all routes of entry during work.
- *Process* or *operation analysis:* the awareness of operations, from raw materials through their transformation to products and by-products, that may result in the release of chemicals or energy that could cause harm.

- ➢ *Maintenance activities, spills,* and *accidents:* the knowledge of acute incidents, infrequent events, leaks, and releases that are missed in routine evaluations.
- ➢ *Epidemiology* and *risk assessment:* a literature review of population-based research and case-based surveillance that may provide information about adverse health effects not yet noticed in a small work force.
- ➢ *Interview:* the information provided by workers, regarding health symptoms, tasks, and changes in conditions, that can provide essential details regarding process analysis, health impact, and other stressors on the job that may be chemical, physical, ergonomic, or biological.
- ➢ *Unequal distribution of risks:* awareness that some populations of workers are more likely to experience increased risks of diseases and injuries in the workplace, e.g., older workers are at greatly increased risk of injury fatality; more partially disabled workers who may require special protection; have been able to re-enter the workplace with protection afforded by the ADA; and increasing numbers of working teens are at higher risk of injury.
- ➢ *Variability of response:* the way individuals vary in their susceptibility because of factors such as age, size, respiratory rate, and general health status. Recognition of the nonuniversality of response helps maintain awareness of possible unrecognized hazards.

The purpose of evaluation is the prevention of hazardous exposures and resulting adverse health effects. Unlike health care providers, whose job is to treat existing conditions, industrial hygienists can prevent illness through recognition and correction of hazards before they cause harm. The industrial hygienist uses many sources of information and methods in evaluating the workplace. The next section describes some of them.

Basic Approach to Hazard Recognition

Almost any work environment has either potential or actual environmental hazards that the health and safety professional must recognize, measure, and monitor. The first step toward recognition of these potential hazards is the consideration of the raw materials being used, including any known impurities, and the potential of those materials to do harm. The next consideration is how these raw materials are modified through intermediate steps. Finally, an evaluation of the finished product or by-products must also be done, both under normal conditions and under anticipated emergency conditions, to determine whether any hazards might exist at this point.

A basic, systematic procedure can be followed in the recognition of occupational health hazards. Hazard recognition methods are similar whether a chemical, physical, or biological agent is involved. Questions should be formulated to organize information:

- ➢ What are the raw materials?
- ➢ What is produced?
- ➢ What intermediate products are formed in the process?
- ➢ What by-products may be released?
- ➢ What are the usual cleaning or maintenance procedures at the end of the day, end of a run, or changeover to another product?
- ➢ What hazardous waste is produced and how is it disposed?

There is a wealth of health and safety information that should be researched to help anticipate potential hazards in any work setting. Included in this search should be a review of the known hazards associated with industrial processes or job classifications. An inventory can then be made of previously identified hazards by category, and any relevant standards or guidelines can be referenced. Armed with this information, the next step is to study the specific operation or process and consider where air contaminants are released, as well as where and when employees are exposed.

Any job can include physical hazards as well as chemical hazards. Energy uses, electromagnetic fields, noise sources, fire hazards, physically demanding tasks, and material-handling jobs must all be noted. Hazards that could result in acute traumatic injuries also include vehicles and sources of energy. Vehicles include automobiles, forklift trucks, and overhead cranes. Energy sources could be mechanical (pneumatic or hydraulic), electrical, thermal, or chemical. The pattern of work may include sitting, standing, or lifting. Physical hazards could also include vibration, radiation, barometric pressure alterations, and hazardous motions or postures that could cause cumulative trauma disorders. Temperature extremes, lighting levels, and machine pacing are additional factors to consider in the initial hazard surveillance approach.

Biological hazards include infectious agents (bacteria, viruses, parasites, and fungi), toxins associated with plants or animals, and pharmacoactive substances such as enzymes, hormones, or other biological materials. Infectious agents include tuberculosis in shelters, clinics, hospitals, or offices; bloodborne pathogens for first aid providers; and mold or mildew in a basement office after a flood. In evaluations of agricultural work areas, one may need to consider other agents. In biotechnology or pharmaceutical companies, exotic endotoxins or biological materials may be employed.

Psychological hazards such as high job demands and low control can cause stress and should also be considered. Some factors that can result in emotional strain include machine pacing; boring, repetitive tasks; complex, highly demanding requirements; shift work; fear of layoffs or physical violence; computer monitoring of performance; and the absence of social or coworker support.

Review of Literature

Prior to evaluating any workplace, it is useful to know what hazards are anticipated. A literature review of the industry in question or the type of operation being done can facilitate this analysis. Recommended general resources include Burgess (1995); Cralley & Cralley (1986, 1986a, & 1986b); the International Labour Organization (ILO) (1983); Weeks et al (1991) Levy & Wegman (2000); and U.S. Department

of Health, Education and Welfare (U.S. DHEW), NIOSH (1977).

Other resources include current publications, review articles in journals; and computer sources such as compact disk, or CD–ROM, services. Sources to be consulted include technical journals in the fields of industrial hygiene, occupational medicine, environmental analysis, and epidemiology. Some trade associations incorporate health and safety articles into their regular communications with members. The National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have published very useful pamphlets, criteria documents, reports, and technical bulletins on many ergonomic subjects, which can be consulted prior to a workplace evaluation. The Office of Technology Assessment (OTA) also has several publications. Most of these are available on their websites under the heading "Publications." The OSHA website is www.osha.gov, and for NIOSH, www.cdc.gov/NIOSH/homepage/html. NIOSH maintains a mailing list to inform interested persons about new publications and courses offered for further training.

Inventory

A list should be prepared of all chemicals present in the facility. The list should include all raw materials and final products. This chemical inventory is required by OSHA's Hazard Communication Standard, 29 *CFR* 1910.1200, for the purpose of anticipating possible hazards and ensuring that these risks are communicated to employers and employees before they are encountered in the workplace. The manufacturer or supplier of each chemical must provide a material safety data sheet (MSDS) for every product.

For every chemical, the relevant standards should be looked up; they cover many of the most hazardous materials currently in use and often highlight possible chemical exposures that must be controlled. The legal standards are OSHA's permissible exposure limits (PELs), which set the maximum boundaries for allowable worker exposures. There are different types of limits. Time-weighted average limits (TWAs) are used to evaluate average sampling results covering a whole shift. Short-term exposure limits (STELs) or ceiling levels are used to evaluate brief exposure times or peak releases.

Although not enforceable by law, other guidelines are often more current and therefore more protective of workers. These include recommended exposure limits (RELs), developed by NIOSH to guide OSHA in promulgating its legal standards, and Threshold Limit Values® (TLVs®), offered by the American Conference of Governmental Industrial Hygienists (ACGIH) annually in a pocket-sized booklet as a guideline for good workplace control. See Appendix B for the 2001 TLVs and BEIs®. A convenient reference for OSHA and NIOSH limits is the NIOSH *Pocket Guide to Chemical Hazards* (1997).

Unfortunately, there are no standards or guidelines for most chemicals that reflect experience or research with them.

Table 15–A. ***Categories of Potential Hazards Found in Hospitals***

Hazard Categories	*Definition*	*Examples Found in the Hospital Setting*
Biological	Infectious/biological agents such as bacteria, viruses,fungi, or parasites, that can be transmitted by contact with infectious patients or with contaminated body secretions/fluids.	Human Immunodeficiency virus (HIV) Hepatitis B or C virus Tuberculosis
Ergonomic	Ergonomics attempts to fit the job to the worker instead of the traditional method of fitting the worker to the job. It is the study of human characteristics, both behavioral and biological, for the appropriate design of the living and working environment.	Lifting patients Lifting supplies/ radiation shields Standing for long periods of time Poor lighting Poor workstation design
Chemical	Chemicals that are potentially toxic or irritating to the body, including medications, gases, laboratory reagents, or cleaning products	Ethylene oxide Formaldehyde Glutaraldehyde Waste anesthetic gases Chemotherapy Pentamidine Ribavirin
Psychological	Factors/situations encountered in the workplace that create or potentiate stress, emotional strain, or interpersonal problems	Stress Workplace hierarchy Shiftwork Fear of layoff Fear of violence
Physical	Physical agents that can cause tissue trauma	Radiation Lasers Noise High voltage equipment Extreme temperatures Needlesticks

It has been estimated that new chemical products are introduced into the workplace at a rate of 1,000 to 3,000 every year, yielding a total of 60,000 chemicals in widespread commercial use in the western nations. Of these, OTA estimates that only 5,000 chemicals have ever been tested for toxicity. Only 454 chemicals have specific limits promulgated by OSHA. Maintenance of a complete inventory helps to provide oversight and to keep track of any previously unrecognized problems and health effects.

The inventory can be extended to include physical, ergonomic, biological, and psychological hazards as well as

chemical ones. For example, see Table 15–A for an inventory of potential hazards in a hospital setting. Any inventory should be maintained, updated, and used to develop, manage, and evaluate the appropriate programs and to ensure awareness of the broad range of hazards that may be present in the workplace.

DESCRIPTION OF PROCESS OR OPERATION

The inventory provides information about the identity of the hazards present, but it cannot indicate the degree of risk from exposure to those materials. It does not quantify the amounts employed in the process; indicate how or where they are used or produced; or detail at what point, via what route, or for how long employees are potentially exposed. The severity of the hazards present depends on the potential for worker contact as well as the duration and concentration of exposure to the hazardous materials; therefore, information about the industrial processes and operations is needed to link the hazardous materials to their use in production and to personnel contact. Facility engineering and manufacturing personnel should be consulted regarding usual operations, abnormal operating conditions, and other factors that can affect exposures.

There are numerous industrial operations that should immediately alert the health and safety professional to a potential health hazard. Lists of industrial operations such as the ones shown in Table 15–B are helpful in reviewing processes that might create special risks such as the aerosolization of a hazardous material. After a list of process operations that possibly produce harmful air contaminants has been prepared, certain operations should be selected for closer scrutiny.

Process Flow Sheet

A simple process flow sheet should be drawn that shows in a stepwise fashion how and where each material is introduced and at what point products and by-products are made (Figure 15–1). Process flow sheets and the standard operating procedures (SOPs) that describe the particular operations involved should be obtained and studied. They not only provide a good description of the general operations involved, but also serve as an excellent source for the terminology used in that particular industry. In many industrial operations, many different hazards exist simultaneously. Therefore, it is

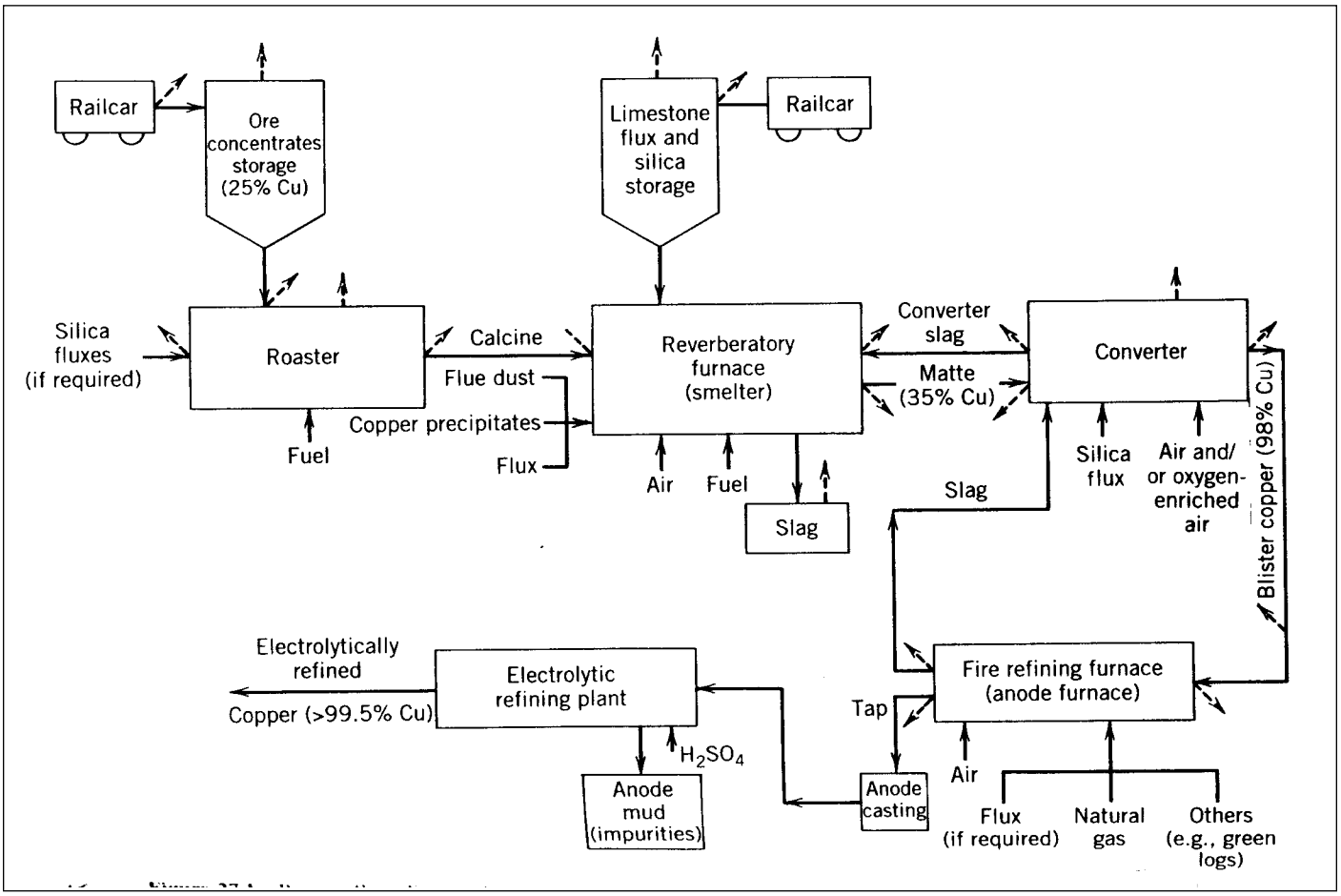

Figure 15–1. Process flow diagram for primary copper smelting showing fugitive emissions. (Source EPA 1977)

Table 15–B. *Common Unit Processes and Associated Hazards by Route of Entry**

Unit Process	*Route of Entry and Hazard*
Abrasive blasting (surface treatment with high velocity sand, steel shot, pecan shells, glass, aluminum oxide, etc.)	Inhalation: silica, metal and paint dust Noise
Acid/alkali treatments (dipping metal parts in open baths to remove oxides, grease, oil, and dirt)	
Acid pickling (with HCl, HNO_3, H_2SO_4, H_2CrO_4, HNO_3/HF)	Inhalation: acid mist Skin contact: burns and corrosion
Acid bright dips (with HNO_3/H_2SO_4)	Inhalation: NO_2, acid mists
Molten caustic descaling	Inhalation: smoke and vapors
Bath (high temperature)	Skin contact: burns
Blending and mixing (powders and/or liquid are mixed to form products, undergo reactions, etc.)	Inhalation: dusts and mists of toxic materials Skin contact: toxic materials
Crushing and sizing (mechanically reducing the particle size of solids and sorting larger from smaller with screens or cyclones)	Inhalation: dust, free silica Noise
Degreasing (removing grease, oil, and dirt from metal and plastic with solvents and cleaners)	Inhalation: vapors Skin contact: dermatitis and absorption
Cold solvent washing (clean parts with ketones, cellosolves, and aliphatic, aromatic, and stoddard solvents)	Fire and explosion (if flammable) Metabolic: carbon monoxide formed from methylene chloride
Vapor degreasers (with trichloroethylene, methyl chloroform, ethylene dichloride, and certain fluorocarbon compounds)	Inhalation: vapors; thermal degradation may form phosgene, hydrogen chloride, and chlorine gases Skin contact: dermatitis and absorption
Electroplating (coating metals, plastics and rubber with thin layers of metals)	Inhalation: acid mists, HCN, alkali mists, chromium mists Skin contact: acids, alkalis Ingestion: cyanide compounds
Copper	
Chromium	
Cadmium	
Gold	
Silver	
Forging (deforming hot or cold metal by presses or hammering)	Inhalation: hydrocarbons in smokes (hot processes) including polyaromatic hydrocarbons, SO_2, CO, NOx, and other metals sprayed on dies (e.g., lead and molybdenum) Heat stress Noise
Furnace operations (melting and refining metals; boilers for steam generation)	Inhalation: metal fumes, combustion gases, e.g., SO_2 and CO Noise from burners Heat stress Infrared radiation, cataracts in eyes
Grinding, polishing, and buffing (an abrasive is used to remove or shape metal or other material)	Inhalation: toxic dusts from both metals and abrasives Noise

(Continues)

Table 15–B. *(Concluded)**

Unit Process	*Route of Entry and Hazard*
Industrial radiography (x-ray or gamma ray sources used to examine parts of equipment)	Radiation exposure
Machining (metals, plastics, or wood are worked or shaped with lathes, drills, planers, or milling machines)	Inhalation: airborne particles, cutting oil mists, toxic metals, nitrosamines formed in some water-based cutting oils Skin contact: cutting oils, solvents, sharp chips Noise
Materials handling and storage (conveyors, forklift trucks are used to move materials to/from storage)	Inhalation: CO, exhaust particulate, dusts from conveyors, emissions from spills or broken containers
Mining (drilling, blasting, mucking to remove loose material and material transport)	Inhalation: silica dust, NO_2 from blasting, gases from the mine Heat stress Noise
Painting and spraying (applications of liquids to surfaces, e.g., paints, pesticides, coatings)	Inhalation: solvents as mists and vapors, toxic materials Skin contact: solvents, toxic materials
Soldering (joining metals with molten alloys of lead or silver)	Inhalation: lead and cadmium particulates ("fumes") and flux fumes
Welding and metal cutting (joining or cutting metals by heating them to molten or semi-molten state) Arc welding Resistance welding Flame cutting and welding Brazing	Inhalation: metal fumes, toxic gases and materials, flux particulates, etc. Noise: from burner Eye and skin damage from infrared and ultraviolet radiation

The health hazards may also depend on the toxicity and physical form(s) (gas, liquid, solid, powder, etc.) of the materials used. For further information see Burgess WA. *Recognition of Health Hazards in Industry: A Review of Materials and Processes*. New York: Wiley, 1981. *(Reprinted with permission from Levy B, Wegman DH. *Occupational Health, Recognizing and Preventing Work-Related Disease*, 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

necessary to carefully examine the overall process so that potentially hazardous conditions are not overlooked.

It is important to identify the air contaminants produced and to pinpoint the location and tasks of personnel that might be exposed to them. Repetitive operations, wherein a worker remains in one location and repeats the same task, can be relatively straightforward to analyze. In operations during which several contaminants are generated, the evaluation process involves identifying the points at which each material is released and the duration of each release, and factoring in the maximum number of times per workshift these exposures occur. This allows prediction of the amount of contaminant potentially released into the environment, and can help target areas for personal or area air sampling. In workplaces where tasks vary from day to day, depending on the products being made, work assignment, and other factors, a process flow sheet may be less useful, and individual assessments are necessary.

Chemical process companies involved with the manufacture of large volumes of chemicals use closed systems. Although chemicals are not routinely released to the atmosphere, exposure to air contaminants in work areas arises from the following:

- ➢ Leaks from joints, fittings, closures, and other components that allow release from the otherwise closed system
- ➢ The process of charging the system or preparing and loading the raw materials
- ➢ Intentional releases of contaminants from vents, process sampling points, or quality control checkpoints
- ➢ Stack gases from combustion processes
- ➢ Accidental or unintentional releases resulting from equipment malfunction or failure
- ➢ Maintenance or repair activities or infrequently performed functions without standard operating procedures

Many valves leak even when they are supposed to be shut, and such leaks can release significant concentrations of chemical

air contaminants. Purges, minor overpressures, and system breathing into the atmosphere should be contained by collection, scrubbing, reaction, incineration, or other measures that safely dispose of the products or eliminate their release altogether. Environmental Protection Agency (EPA) emission requirements may require further control measures. Efforts by the environmental movement have influenced state and local legislation to discourage the use of hazardous materials completely. These toxic use reduction (TUR) efforts have emphasized review of chemical operations to eliminate or reduce the use of hazardous chemicals and substitute safer materials wherever possible.

Checklists

A checklist for evaluating environmental hazards that can arise from industrial operations is presented here. It should be modified to fit each particular situation.

Overall Process or Operation

List all hazardous chemical or physical agents used or formed in the process. Carry out the following tasks, answering all of the appropriate questions:

- ❑ List the conditions necessary for the agent to be released into the workroom atmosphere. Does it usually occur in the process as a dust, mist, gas, fume, vapor, a low-volatile liquid, or a solid (Table 15–C)? What process conditions could cause material to be sprayed or discharged into the air as a liquid aerosol or dust cloud? Have the consequences of the exposure of raw materials or intermediates on people or operations been considered? Are incompatible materials, such as acids and cyanides in plating operations, kept separate from one another?
- ❑ Review storage of raw materials and finished product. Are unstable materials such as methyl ethyl ketone peroxide properly stored? Have chemical incompatibilities been considered? Are containers appropriate? Has flammability been considered?
- ❑ Consider transport and disposal. Have provisions been made for the safe disposal of toxic materials in compliance with all relevant regulations? Can reactants be removed and disposed of promptly in an emergency? Can spills be quickly and effectively contained?
- ❑ List the background airborne concentration levels in the workroom that would usually be present as a function of time. List the peak airborne concentrations as a function of task duration. List the appropriate PELs, RELs, TLVs®, and STELs.
- ❑ Review fire safety. Are fire extinguishers the correct type and size for the materials present? Are they inspected and recharged on a scheduled basis? Are the extinguishing agents compatible with process materials? Is an evacuation plan prepared and disseminated? Are alarms visible, audible, and understandable? Are employees trained in fire safety? Do they know where emergency equipment is located?
- ❑ List the levels of those physical agents that are normally present (such as ionizing and nonionizing radiation,

Table 15–C. *Potentially Hazardous Operations and Air Contaminants*

Process Types	*Contaminant Type*	*Contaminant Examples*
Hot operations		
Welding	Gases (g)	Chromates (p)
Chemical reactions	Particulates (p)	Zinc and compounds (p)
Soldering	(Dusts, fumes, mists)	Manganese and compounds (p)
Melting		Metal oxides (p)
Molding		Carbon monoxide (g)
Burning		Ozone (g)
		Cadmium oxide (p)
		Fluorides (p)
		Lead (p)
		Vinyl chloride (g)
Liquid operations		
Painting	Vapors (v)	Benzene (v)
Degreasing	Gases (g)	Trichloroethylene (v)
Dipping	Mists (m)	Methylene chloride (v)
Spraying		1,1,1-trichloroethylene (v)
Brushing		Hydrochloric acid (m)
Coating		Sulfuric acid (m)
Etching		Hydrogen chloride (g)
Cleaning		Cyanide salts (m)
Dry cleaning		Chromic acid (m)
Pickling		Hydrogen cyanide (g)
Plating		TDI, MDI (v)
Mixing		Hydrogen sulfide (g)
Galvanizing		Sulfur dioxide (g)
Chemical reactions		Carbon tetrachloride (v)
Solid operations		
Pouring	Dusts (d)	Cement
Mixing		Quartz (free silica)
Separations		Fibrous glass
Extraction		
Crushing		
Conveying		
Loading		
Bagging		
Pressurized spraying		
Cleaning parts	Vapors (v)	Organic solvents (v)
Applying pesticides	Dusts (d)	Chlordane (m)
Degreasing	Mists (m)	Parathion (m)
Sand blasting		Trichloroethylene (v)
Painting		1,1,1-trichloroethane (v)
		Methylene chloride (v)
		Quartz (free silica, d)
Shaping operations		
Cutting	Dusts (d)	Asbestos
Grinding		Beryllium
Filing		Uranium
Milling		Zinc
Molding		Lead
Sawing		
Drilling		

Note: d = dusts, g = gases, m = mists, p = particulates, v = vapors.
(Reprinted from *Occupational Exposure Sampling Strategy Manual*, NIOSH Pub. No. 77-173.)

temperature extremes, vibration, and noise). List any relevant standards or guidelines.

EQUIPMENT

Conduct all of the following procedures, listing those pieces of equipment that contain sufficient hazardous material or energy such that a hazard would be produced if their contents were suddenly released to the environment:

- ❑ List the equipment that could release hazardous levels of physical agents during normal operations or abnormal situations such as power outages.
- ❑ List the equipment that can produce hazardous concentrations of airborne contaminants. For each item indicate the control measures installed to minimize the hazard. Is the health and safety control measure adequate, fail-safe, and reliable? Is it checked on a routine basis?
- ❑ List process equipment with components that are likely to fail due to corrosion or to leak hazardous materials such as valves, pump packing, and tank vents. What safeguards have been taken to prevent expected leakage? Is each safeguard adequate, fail-safe, and reliable? Is there a preventive maintenance program in place to ensure routine examination and replacement of these components?
- ❑ Label all chemical containers, transport vessels, and piping systems in accordance with the OSHA hazard communication standard. Are labels appropriate for the literacy level and language of the work force?
- ❑ Ensure that all equipment can be correctly locked out and tagged out during necessary procedures. Are emergency disconnect switches properly marked?

CLEANING METHODS

Cleaning operations should be noted to identify hazardous materials and processes. The primary cleaning methods used in industry include the following:

- ❑ Manual wiping of parts or equipment with a solvent-soaked rag
- ❑ Chemical stripping, degreasing, or removal by dissolving
- ❑ Use of hand-held or mechanical brushes
- ❑ Scraping or sanding
- ❑ Dry sweeping or wet mopping
- ❑ Wet sponging
- ❑ Abrasive blasting
- ❑ Steam cleaning
- ❑ Using compressed air to blow off dust
- ❑ Using vacuum-cleaning devices

The common feature of all these operations is that by some physical and/or chemical action a contaminant is dislodged from the surface to which it was adhering and could be released into the work environment. In addition the cleaning agent used to remove a hazardous material might introduce another, equally hazardous, chemical into the workplace.

For example, cleaning chemicals and disinfectants have been associated with work-related asthma. Surveillance of work-related asthma was funded by NIOSH in four states. The results indicated that cleaning materials were the fifth most frequently reported cause of asthma cases, including both new-onset asthma and work-aggravated asthma. Cleaning agents and disinfectants may contain strong irritants (e.g. chlorine, ammonia) or sensitizers (e.g. benzalkonium chloride, formaldehyde, chlorhexidine). Similarly, rag cleaning with organic solvents results in worker exposure to organic vapors, by inhalation and byskin contact. A brush used to sweep up dusty substances or a scraper used to dislodge built-up cakes of dry substances can disperse dust into the air. The use of compressed air to blow dust from surfaces reentrains dust that had settled out and will probably produce the greatest concentration of air contaminants. OSHA regulations prohibit the use of compressed air to clean except when the pressure is reduced to 30 psi, and then only if an effective chip guard and personal protective equipment are used. The use of compressed air with asbestos dust is forbidden.

High-pressure water blasting and steam cleaning are essentially wet methods that might initially appear to be designed to suppress the generation of air contaminants. However, hydroblasting equipment to remove a solid can produce substantial concentrations of air contaminants, as can steam cleaning, because of the temperatures and forces involved.

The use of vacuum cleaners, which collect and contain material for removal, appears to be the most satisfactory method of cleaning dry, dusty materials without producing excessive amounts of contaminants. However, a special vacuum with a high-efficiency particulate filter (HEPA) is needed when dealing with certain highly toxic dusts such as asbestos, lead, arsenic, or cadmium. HEPA vacuuming is often accompanied by low pressure, wet methods such as misting or airless spraying, in order to keep levels of airborne toxic dusts to a minimum.

A preferable step is to reduce the dispersal of airborne dusts in the first place. Some power sanders and soldering guns can be specially fitted for dust or fume removal at the point of generation. The need for cleaning can sometimes be further reduced by analysis of the source of the material that must be removed. For example, degreasing is not necessary if oil or coolant is not applied to a part in the first place. A toxics use reduction approach would seek to identify and prevent the source of the contamination, if possible, and then use the safest method to remove it; for example, with a water-based cleaner rather than a volatile organic solvent.

Process Safety Management

Inherent in the use or storage of large quantities of highly hazardous or flammable chemicals is the risk of catastrophic releases that would prove injurious or fatal both to employees and to those living in the immediate vicinity of the facility. On Dec. 2, 1984, methyl isocyanate was released from Union Carbide's pesticide plant in Bhopal, India, which

caused at least 6,500 deaths and an estimated 20,000 to 50,000 serious injuries. This experience taught the world a tragic lesson about worker and community consequences of an unexpected chemical release and the need for controls and emergency preparedness.

Process safety management is a systematic approach to evaluating an entire process for the purpose of preventing such unwanted releases of hazardous chemicals into locations that could expose employees and others to serious hazards. In 1992, OSHA promulgated a standard for general industry, 29 *CFR* 1910.119, which mandates process safety management of highly hazardous chemicals for companies that use or store large quantities of flammable or highly hazardous chemicals in one location. It requires them to implement a program that incorporates analyses, written operating procedures, training, inspection and testing, and safety reviews for their own employees and for contractors. OSHA defines process safety management as the proactive identification, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in process, procedures, or equipment.

OSHA acknowledges several methods to evaluate hazards of the process being analyzed: What-if scenarios, checklists, what-ifs in a checklist format, hazard and operability studies (HAZOPs), failure mode and effects analysis (FMEA), fault tree analysis, or other equivalent methods are all acceptable. Employers are required to determine and document the priority order for conducting process-hazard analyses based on a rationale that considers the extent of the process-hazards, the number of potentially affected employees, the age of the processes, and the facility's operating history.

This approach requires the development of expertise, experience, and proactive initiative by a team of concerned individuals. These are attained primarily by conducting process-hazard analyses, directed toward evaluating potential causes and consequences of fires, explosions, releases of toxic or flammable chemicals, and major spills of hazardous chemicals. The health and safety professional, with the assistance of process managers, employees, and others, must determine the potential failure points or modes in a process. The focus is on equipment, instrumentation, utilities, human actions (routine and nonroutine), and external factors that might impact the process.

For the health and safety professional, a process-hazard analysis can provide a starting point in an overall hazard evaluation. Such analyses should be performed whenever possible. For those evaluating businesses where quantities of hazardous materials in use fall below the OSHA requirements for a written plan, the guidelines contained in the Process Safety Standard may still serve as a useful tool in the evaluation process.

FIELD SURVEY

Thus far in the evaluation process, most of the research recommended has probably been conducted outside of the workplace. Process diagrams, literature searches, and inventories can be reviewed in the office, but evaluation requires on-site, direct observation, measurement, and assessment. It is at this point that the anticipation of hazards must be integrated with actual conditions. Whether the motivation for the evaluation is compliance, insurance, expert testimony, complaint investigation, or development of a comprehensive health and safety plan, direct, on-site involvement on the part of the industrial hygienist is required. This usually begins with a walkthrough of the workplace.

The walkthrough, or initial field survey, follows the flow of materials into the facility, through all the various processes involved in the operation, to the shipping of finished product, as well as tracking unwanted by-products. It should also include nonproduct areas such as maintenance and other service operations. It should be conducted with the facility or process manager, someone familiar with both the process design and usual operations. The walkthrough introduces the industrial hygienist to the language of facility operations, establishes a baseline of current conditions, and allows an initial assessment of hazards or areas that may require further evaluation.

The industrial hygienist can use this opportunity to meet operators of key processes, area supervisors, and other health and safety personnel. Communication with these individuals is essential to understanding the sources and effects of hazards on the job, and for planning future sampling and analyses. A checklist, a sketch of the facility layout, preliminary notes, or a tape recording is useful for documenting initial impressions and serves as a reminder to return to areas that require more intensive inspection.

As our society becomes more and more service oriented, the traditional facility tour may be conducted less frequently. The field survey will, however, remain a vital tool of the industrial hygienist, with the focus of the initial walkthrough being individual operations within a building. Conducting the initial assessment of the operation with an area supervisor who can help obtain a sketch of the physical operation of interest and familiarize the industrial hygienist with the current problems will remain invaluable, as will developing a checklist to use in the walkthrough itself.

Sensory Perception

Field surveys also allow industrial hygienists to make use of their sensory perceptions (vision, hearing, and sense of smell) to note potential hazards. Observing dusty operations, patterns of shavings or powder on the floor (Figure 15–2), overspray on walls, puddles underneath valves, or wetness around an area not currently in use alerts the industrial hygienist to problems not considered before. The exact location of processes of concern, such as welding stations, degreasers, flammable storage, exits, and break areas can be precisely located and added to the facility layout for later consideration.

The absence or presence of visible dust should not sway initial judgment excessively. Because dust particles of respirable size are not visible to the unaided eye, lack of a visible dust

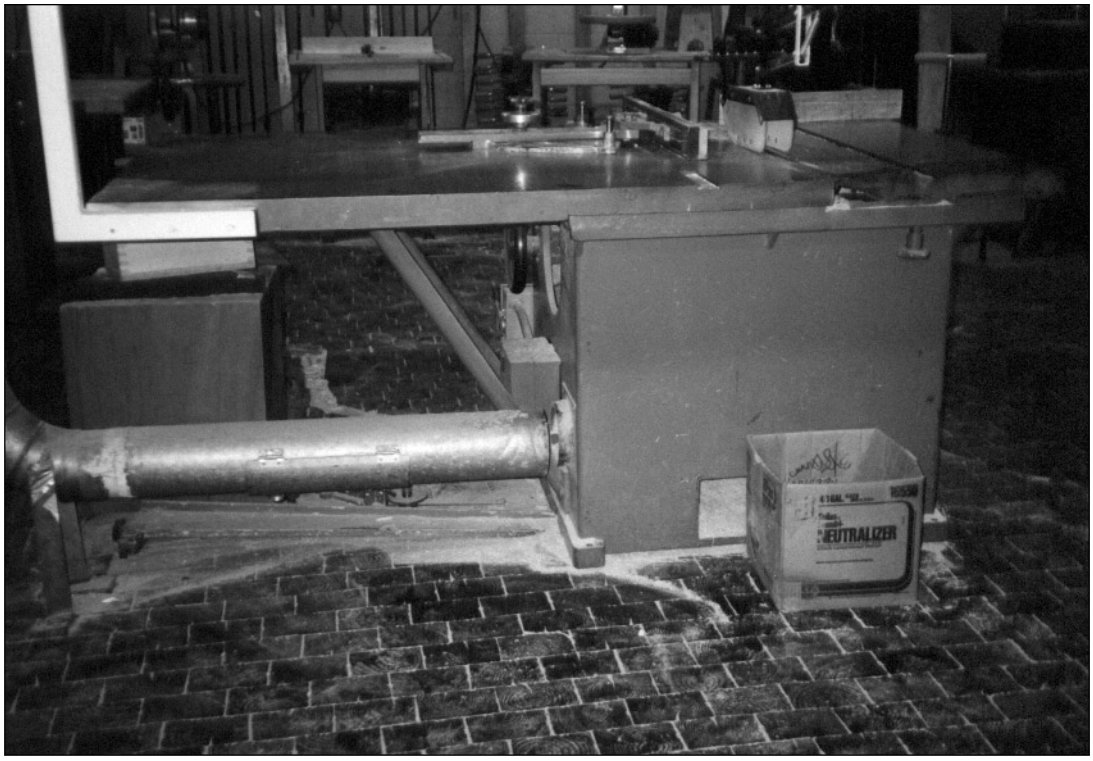

Figure 15–2. Observing dusty operations, patterns of shavings or powder on the floor, overspray on walls, puddles underneath valves, or wetness around an area not currently in use alerts the industrial hygienist to problems not considered before. The pattern of wood dust under this saw indicated that the local exhaust ventilation was disconnected. (Photo by Elise Pechter)

cloud does not guarantee an atmosphere free of respiratory hazards. Timing of dry sweeping and shaking out of dust collection devices should be noted. The need for air sampling for dusts should be determined by the source, identity, toxicity, health complaints, and processes of concern.

Whenever the tour guide must move closer to the industrial hygienist in order to be understood, it is likely that noise levels are excessive and this fact should be noted. Patterns of hearing protector use should also be recorded during the walkthrough.

The presence of many vapors and gases is detectable by smell. The odor thresholds for some chemicals are in the parts per billion range, which helps serve as an early warning of exposure. This is especially true for someone entering an area from elsewhere and for certain aromatic or strong-smelling chemicals such as ethyl acrylate or hydrogen sulfide. The sense of smell fatigues with time and is variable from person to person. Odor thresholds listed in resource tables can vary by a factor of 100 from one person to another. Detecting an odor or experiencing eye or throat irritation should indicate to the occupational health professional that a chemical is present to some degree in the air, and an attempt should be made to identify the process or chemical. These sensory impressions do not necessarily reveal an overexposure, but they can provide important clues to a potentially hazardous source. Also, it is important to note that absence of an odor or irritation does not necessarily mean the absence of a chemical exposure.

Control Measures in Use

During the walkthrough or initial field survey, the types, locations, and effectiveness of control measures should be appraised. Controls include local exhaust and general dilution ventilation, shielding, and personal protective equipment such as gloves, respirators, hearing protectors, and safety glasses. Storage of respirators and availability of replacement cartridges are good indicators of a company's oversight of their respirator program.

Ventilation design should be appropriate for the hazard and the process. Homemade ventilation may be inadequate. For example, it might consist of a canopy hood for unheated processes or of hoods distant from the source, both of which would provide less than adequate capture velocity. Ventilation and airflow patterns can be visualized with an air current tube or estimated by taking air velocity measurements. The distance between the air collection device and source should be observed, and any turbulence created by portable fans or locations on aisles should be recorded.

Administrative controls such as job rotation, scheduling of particularly hazardous operations during shifts when fewer workers are present, enforcement of lock-out/tag-out, etc., are not always obvious; questions regarding these types of controls should be included on any questionnaire.

Observation and Interview

Observation and interviews with workers can reveal the best information regarding hazard evaluation and adequacy of controls. During the walkthrough, or while conducting sampling, the occupational health professional must carefully observe workers performing their jobs and note all opportunities for exposure by each route of entry. Without jeopardizing worker confidentiality, employees should be interviewed regarding the

Table 15–D. *Checklist for Evaluating Chemical Exposure*

A. Evaluate the Potential for Airborne Exposure.

1. *Exposure Sources* (rank high/medium/low):
   a. Types and amounts of chemicals in use or created by combustion or decomposition.
   b. Visible leaks, spills, or emissions from process equipment, vents, stacks, or from containers.
   c. Settled dust, which may be resuspended into the air.
   d. Open containers from which liquids may evaporate.
   e. Heating or drying, which may make a chemical more volatile or dusty.
   f. Odors. Consult an odor threshold table to get an estimate of concentration.
   g. Do air monitoring where the presence of a contaminant is suspected but cannot be verified by sight or smell.
   h. Visualize exposure by taking photographs or videotape.
2. *Job Functions* (estimate hours/day):
   a. Manual handling in general.
   b. Active verb job tasks such as grinding, scraping, sawing, cutting, sanding, drilling, spraying, measuring, mixing, blending, dumping, sweeping, wiping, pouring, crushing, filtering, extracting, packaging.
3. *Control Failures:*
   a. Visible leaks from ventilation hoods, ductwork, collectors.
   b. Hoods that are located too far from the source or are missing or broken.
   c. Ductwork that is clogged, dented or has holes.
   d. Insufficient make-up air to replace exhausted air.
   e. Contamination inside respirators.
   f. Improperly selected, maintained, or used respirator.
   g. Lack of or inadequate housekeeping equipment.
   h. Lack of or inadequate doffing and laundering procedures for clothing contaminated by dust.

B. Evaluate the Potential for Accidental Ingestion.

1. *Exposure Sources* (rank high/medium/low):
   a. Types and amounts of chemicals in use or created by combustion or decomposition. Solids are of primary concern.
   b. Contamination of work surfaces, which may spread to food, beverage, gum, cigarettes, hands or face.
   c. Contamination of hands or face, which may enter mouth.
   d. Do wipe sampling to verify the presence of a contaminant on work surfaces, hands, face, and so forth.
2. *Control Failures:*
   a. Contamination of inside of respirator, which may enter mouth.
   b. Contamination of lunchroom surfaces, which may spread to food, beverage, gum, cigarettes, hands or face.

C. Evaluate the Potential for Skin Contact and Absorption.

1. *Exposure Sources:*
   a. Types and amounts of chemicals in use or created by combustion or decomposition. Check dermal absorption potential. Do not rely on OSHA skin notations. Assume most liquids will penetrate skin.
   b. Consider whether one chemical can act as a carrier for other chemicals.
   c. Visualize dermal exposure by taking photographs or videotape.
2. *Job Functions:*
   a. Dipping hands into material.
   b. Handling of wet objects or rags.
3. *Control Failures:*
   a. Contamination of inside of gloves.
   b. Improperly selected, maintained, or used gloves.
   c. Improperly selected, maintained, or used chemical protective clothing.
   d. Lack of or inadequate facilities for washing of hands and face close to work areas.
   e. Lack of or inadequate shower facilities.

(Reprinted from *NewSolutions*, Spring 1991, p. 77, P.O. Box 281200, Lakewood, CO 80228-8200.)

content of their jobs, how they spend their time, exposures of concern, and any health symptoms, especially as they relate to contact with various chemical products or processes. Identifying particularly hazardous operations may be possible by a review of recent incidents. Documenting variations in production levels, assignments, shifts, seasonal work, and ventilation patterns helps in determining when peak exposures might occur and where sampling would be most useful (Table 15–D).

MONITORING AND SAMPLING

Rationale

There are a number of reasons why environmental measurements should be taken in the workplace. Of primary concern to the health and safety professional is evaluating the degree of employee exposure to hazardous materials on the job. Other important reasons include identification of the tasks

Figure 15–3. In personal monitoring, the measurement device, or dosimeter, is placed as close as possible to the contaminant's route of entry into the body. For example, when monitoring an air contaminant that is toxic if inhaled, the measurement device, or dosimeter, is placed on the employee's lapel or as close to the breathing zone as possible. When monitoring noise, the dosimeter should be placed close to the ear. (Photo by Elise Pechter)

or processes that could be sources of peak exposures, evaluation of the impact of process changes and control measures, and compliance with occupational and environmental regulations. Environmental sampling can be used to clear an area for reoccupancy, decide if a confined space is safe for entry, establish background or usual concentrations, or warn of a peak release of a hazardous product.

Monitoring

Monitoring is a continuous program of observation, measurement, and judgment. It requires an awareness of the presence of potential health hazards as processes undergo change, and constant assessment of the adequacy of the control measures in place.

Monitoring is more than simply sampling the air to which an employee is exposed or examining the medical status of that employee. It is a combination of observation, interview, and measurement that permits a judgment to be made relative to the potential hazards and the adequacy of protection afforded employees. Included in the process are both personal and environmental monitoring, performed during a given operation where hazardous materials may be released, and follow-up biological and medical monitoring of the employees involved in that process.

PERSONAL MONITORING

Personal monitoring is the measurement of a particular employee's exposure to airborne contaminants and, in theory, reflects actual exposure to the employee. It is usually done during a specific time period, often an 8-hour shift or a 15-minute period, to ensure compliance with OSHA PELs or STELs; it can therefore include times when the employee is at break or involved in activities where the contaminant of interest is not in use. It is because of this variability that it is extremely important to observe individuals being monitored and to interview them about their work, before, during, and after the monitoring is done.

In personal monitoring, the measurement device, or dosimeter, is placed as close as possible to the contaminant's route of entry into the body. (Figure 15–3). For example, when monitoring an air contaminant that is toxic if inhaled, the measurement device is placed on the employee's lapel or as close to the breathing zone as possible. When monitoring noise, the dosimeter should be placed close to the ear.

Even with the proper placement of the dosimeter, there is no guarantee that results of personal sampling will reflect actual exposure levels. Some materials are absorbed through the skin or mucous membranes in addition to being inhaled. The release of contaminants is often not uniform, and the side of the employee where the monitor is placed may not be the side closest to the point of release of the contaminant. The results would therefore underestimate the exposure. On the other hand, if the sampling device is placed outside a respirator or face shield, the result might overestimate the true exposure to the worker.

Personal sampling relies on portable, battery-operated sampling pumps that the employee wears throughout the sampling. This offers freedom of movement because there is no need to maintain proximity to electrical outlets. The pumps, however, can be noisy and heavy, and employees are sometimes not willing to wear them on a continuous basis. In addition, because the pumps are battery operated, they

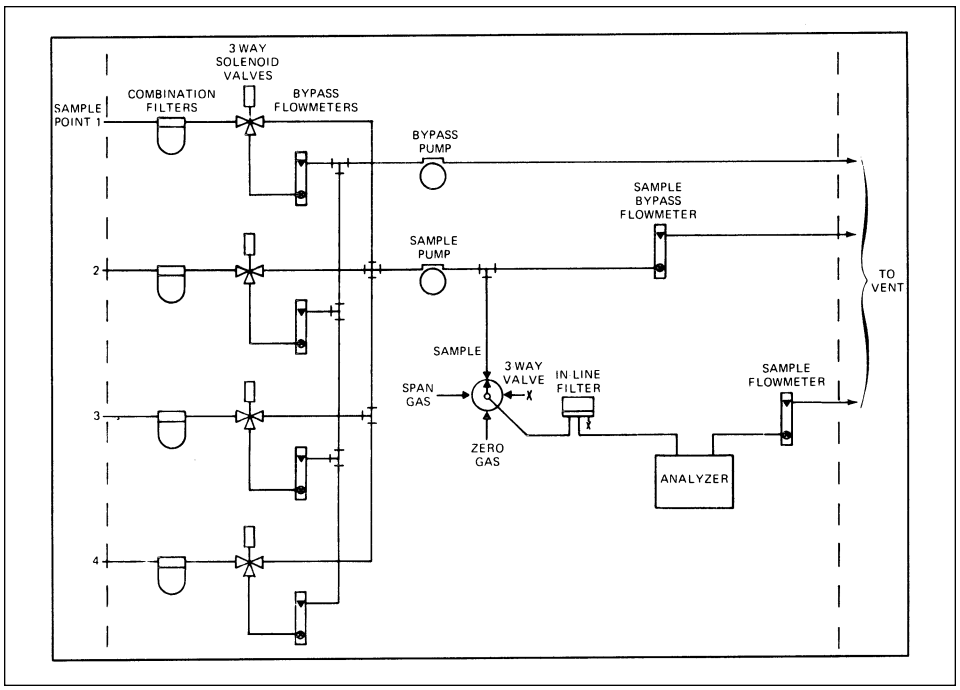

Figure 15–4. Centralized analytical devices can be attached to remote probes so that data can be acquired from several areas simultaneously and monitored from a central location.

might have a variable output throughout the day, or might actually stop operating in the middle of sampling. The effective use of personal sampling pumps relies on proper calibration and maintenance and consistent supervision by well-trained professionals during the monitoring process.

AREA MONITORING

Area sampling is another method used by industrial hygienists to evaluate exposure. Here, however, exposure is measured not in terms of a particular employee, but rather in terms of the ambient air concentration of a particular substance in a given area at a given period of time. The measurement device, which does not have to be battery operated and can be larger and more rugged than those used in personal sampling, is placed adjacent to a worker's normal workstation. Centralized analytical devices can be attached to remote probes so that data can be acquired from several areas simultaneously and monitored from a central location (Figure 15–4). An alarm can be sounded if a preset limit is exceeded (as shown in Figure 15–5). Area sampling is an important technique to determine the need to develop, implement, or improve control measures.

Ideally, area sampling would be so thorough and the pattern of potential exposure to workers so well defined that, in any given work space, knowledge of a worker's activity would be sufficient to estimate that person's exposure, and personal monitoring would not be necessary. If, for instance, vapor concentrations and their duration around equipment were known and could be superimposed on a floor plan, then a worker's exposure could be determined from observing that worker's movements and plotting the frequency and duration spent in each area. The employee's daily exposure could then be found by adding short-term exposures to compute the time-weighted average (TWA). This in-depth area exposure analysis is not routinely done, however. It requires a tremendous amount of time and monitoring equipment and may still miss crucial contributions to a worker's exposure on any given day.

In most processes, airborne concentrations of materials usually vary over time. The fluctuations may be large, and continue for hours, or they may be brief, sometimes lasting only seconds or minutes. Only extensive, continuous sampling can provide information about such fluctuations in any given location. The data, if collected with a real-time monitor

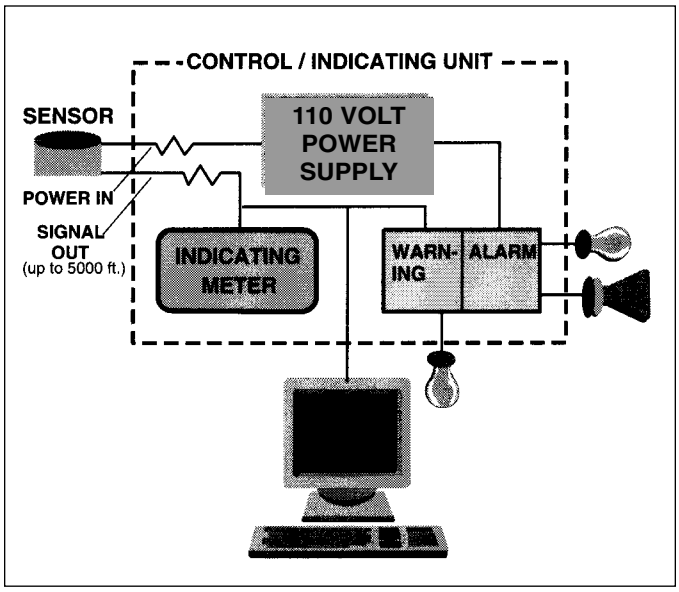

Figure 15–5. An alarm can be sounded if a preset limit is exceeded.

or printed on a strip-chart recorder, provide valuable clues about the main sources and timing of exposure, and thus a means to design controls that should be used in a process. The computer printout or strip chart can be used to estimate an individual's exposure and can also serve as a historical record.

Area sampling is also used to establish usual background concentrations for chemicals that are ubiquitous in our environment. An incident that occurred in Boston, Massachusetts, illustrates this rationale. A transformer fire released polychlorinated biphenyls (PCBs) into an office basement and ventilation system in October 1981. In June 1985 a new tenant, prior to occupying the building, performed testing that revealed contamination, including dioxins and dibenzofurans, which required extensive cleaning. Sampling methods were so sensitive, and the chemicals so persistent, that they were detected, even after thorough cleaning, four years after the incident. Questions about the adequacy of the cleanup and the attendant risk led researchers to consider what normal background concentrations in similar settings might be. In order to establish normal background concentration levels, area air sampling was conducted in similar buildings with no history of PCB release. These results were subsequently used to develop a criterion for reentry into a previously contaminated area, with assurance that the exposure and risk would be no greater than usual (U.S. Department of Health & Human Services [U.S. DHHS], NIOSH, 1987, 1988). Area sampling for the same purpose is used after asbestos or lead abatement in commercial or residential settings.

Area sampling has its disadvantages, though. Sampling equipment can be made rugged and reliable, but often it is not, and leaving it unattended for hours or days at a time without the supervision of a trained technician could result in no reliable data collection during a crucial period in the process. Area sampling may underestimate exposure if the worker works close to a process but the measurement probe or collection device is at a farther distance from the exposure point.

BIOLOGICAL MONITORING AND MEDICAL SCREENING

Biological monitoring is a tool that can be used to assess workers' total exposure to chemicals, or provide information about the impact of workplace hazards on health. Air sampling evaluates the inhalation hazard; measurement of an individual's exhaled air, blood, or urine can provide information about absorption of hazardous materials by all routes of exposure and the physiological effect of the total dose.

In general, there are three categories of biological monitoring: measurement of the contaminant itself, measurement of a metabolite of the chemical, and measurement of enzymes or functions that reflect harm caused by a hazardous exposure.

The most direct approach measures the contaminant itself in blood or urine; this method is used with lead, mercury, cadmium, and arsenic. Carbon monoxide may be mesured in exhaled air. Often, the hazardous chemical cannot be measured directly, but a metabolite can be. For example, methylene chloride is metabolized to carboxyhemoglobin in the human body, and elevated carboxyhemoglobin levels in the blood could reveal overexposure to methylene chloride. Another example is styrene, for which exposure and absorption can be evaluated by the concentration of mandelic acid in urine at the end of a workshift.

Sometimes the adverse effect of a workplace exposure is only revealed when medical evaluation reveals an unusual laboratory result or abnormal function test. These are usually ordered to help diagnose a health problem. For example, a pulmonary function test on an autobody spray painter with a cough can reveal deficits in forced expiratory volume. Such a reduced ability to exhale may be a marker of occupational asthma caused by contact with the isocyanates in polyurethane paint.

Another medical test result that may indicate occupational injury or disease is a slowed nerve conduction velocity, which may be done to help diagnose numbness and tingling in the hands. Slowed conduction (prolonged time) may indicate trauma, repetitive strain, or peripheral neuropathy. Abnormal liver function enzymes may reflect hepatitis or liver injury from chronic solvent exposure. Such results reveal a disease process or harm but do not necessarily indicate the cause of the harm, which also may be attributable to factors outside the workplace or to unrelated medical conditions. Therefore, the results are nonspecific and require interpretation by a trained occupational physician or occupational health nurse. Unfortunately, many physicians have not been trained to identify the occupational or environmental causes of diseases, and some fail to ask their patients about their work and exposure hazards. For example, abdominal pain, insomnia, infertility, and high blood pressure may never be linked diagnostically to the lead poisoning that caused them.

Interest in biological monitoring has increased recently. The American Industrial Hygiene Association (AIHA) wrote a position statement (1999) calling for the incorporation of requirements for biological monitoring into more OSHA standards. With 800,000 work-related illnesses each year, they reasoned, PELs to limit inhalation exposures have not prevented occupational disease. AIHA calls for biological monitoring as an inexpensive, practical, effective hazard assessment tool, as used in Germany and England. The Social Concerns Committee of AIHA countered that biological monitoring is limited in its usefulness because of issues limiting interpretation of the results, as well as privacy, confidentiality, invasiveness, and worker acceptance issues.

The values measured can be compared to background population values or to reference values such as the ACGIH Biological Exposure Indices®, in the same way air-sampling data are evaluated. If conducted side-by-side with industrial hygiene sampling, then biological results may be correlated with airborne concentratrions. This information is useful in etiologcial research and in demonstrating health effects at concentrations of chemical previously thought to be acceptable.

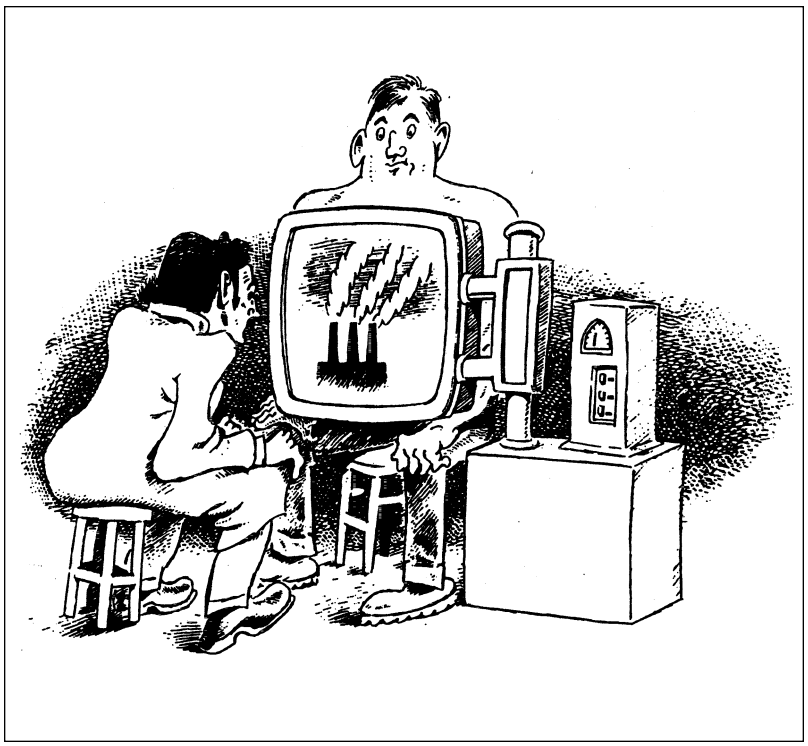

Figure 15–6. Physicians and other health professionals have a vital role in recognizing occupational disease. Contrary to the drawing, there is no simple test. The suspicion and the determination of work-relatedness depend primarily on a careful occupational history. (Drawing by Nick Thorkelson.) (Reprinted with permission from Levy B, Wegman DH. *Occupational Health, Recognizing and Preventing Work-Related Disease,* 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

The test must be reproducible, as well as sensitive and specific to be sure that true positives (people with an adverse health effect or disease) and negatives (those without disease) are identified. See the section, "Required accuracy and precision" about these same issues in relation to air sampling testing. The laboratories must be proficient and certified and participate in laboratory quality control programs. The interpretation of test results may be difficult. The usefulness of the biological test may be limited by:

- ➢ Few validated tests
- ➢ Laboratory reliability
- ➢ Interindividual variability
- ➢ Intraindividual variability
- ➢ Timing of testing may not be appropriate. Value may reflect a peak exposure or a valley from time away from work or clearance of the chemical from the body. Knowledge of the metabolism and half-life of the chemical are required
- ➢ Wide range of normal values in the population
- ➢ Background levels are elevated for many who are not occupationally exposed (see the ACGIH BEI® notation "B")
- ➢ Biological indicator may be nonspecific (see the ACGIH BEI notation "Ns")
- ➢ Quantitative interpretation is ambiguous (see ACGIH BEI notations "Nq" and "Sq")
- ➢ Biological value may indicate exposure and uptake have occurred, but the health consequences are unknown

Biological monitoring may be an important component for evaluating illness and linking symptoms to exposures, but caution should be exercised in its use and interpretation.The significance of results from biological monitoring is open to interpretation; alterations in function or unusual laboratory findings can be viewed as evidence of harm, or they can be viewed as only a marker that exposure has occurred. For example, the indication on chest x-ray films of pleural plaques (small, hard, plate-like surfaces on the pleura), which can exist in the absence of disease is a marker of past asbestos exposure. Interpretation of radiological findings in the lungs is known to be inconsistent; abnormalities are difficult to detect and even more difficult to interpret, so x-ray films should not be the sole determinant in diagnosis of occupational disease (Figure 15–6). There is no simple test to diagnose occupational disease.

Guidelines for biological monitoring must reflect an understanding of the biochemical dynamics of the contaminant in relation to physiological processes. Measurements may represent peak exposures and absorption prior to any significant clearance, or they may reflect equilibrium levels attained only after steady state has been reached. Obtaining information about the relationship between the timing of exposure and biological testing is very important.

For example, lead concentration in blood is used as an index of lead exposure by inhalation and ingestion in the previous days or weeks, whereas zinc protoporphyrin (ZPP) is used as a measure of lead exposure during the previous three or four months. Research shows that bone x-ray fluorescence (XRF) (Hu, 1998; Hu et al, 1989) may reveal the total body burden of lead, including that portion stored in the skeleton. These measurements can be used to identify hazardous exposures, dangerous work practices, or inadequacies in ventilation and personal protective equipment. Differences in blood lead and ZPP concentrations provide

information about the timing of exposure and which tasks pose the greatest risk. Blood lead values can be used to identify individuals at risk, who should be removed from any further exposure.

Medical surveillance. Medical surveillance can extend beyond biological monitoring of individuals to incorporate screening of exposed populations for the adverse effects of those exposures. For example, audiometric testing can be used to determine the extent of temporary or permanent shifts in thresholds of hearing acuity caused by noise exposure. Liver enzymes can be measured to assess the effect of solvents suspected of causing hepatitis or other liver injury. The appearance of the lungs on x-ray films can reveal pneumoconiosis, hypersensitivity pneumonitis, or other respiratory diseases. Baseline skin testing, followed by further skin testing after a potential exposure, is essential for those working in health care or other occupations at high risk for exposure to tuberculosis. Positive changes from baseline should lead to further evaluation or medical treatment.

One purpose of medical surveillance is the early detection of disease or conditions for which treatment can prevent further illness. The affected individual should be removed from the hazardous exposure and receive needed medical treatment and supervision. OSHA has incorporated this concept of medical removal protection (MRP) in its standards to protect workers overexposed to lead and cadmium. OSHA requires that if a worker's medical evaluation indicates overexposure or the adverse health effects associated with these substances, the employer must either provide alternative work in an area where there is no risk of exposure or allow the employee to stay home with full compensation during the period of treatment.

Medical screening can also be an invaluable preventive tool in hazard control. For example, regular testing of urine for mercury in an exposed worker population allows identification of individual workstations or work practice sources. Routine analysis of the group may allow early detection of subtle increases in mercury absorption that might reflect a breakdown in controls or a weakness in the training program.

OSHA has proposed that medical screening and evaluation be used to measure the effectiveness of its PELs. If workers exhibit adverse health effects, while at the same time air-sampling results show compliance with OSHA's standards, then OSHA will use the results to reexamine the adequacy of the PEL.

Over 20 OSHA standards now have requirements for medical examinations or tests, focusing on either medical screening of individuals or surveillance of an entire exposed group (Table 15–E). The medical evaluation required may involve screening of an exposed employee group for an individual agent, or it may include a more comprehensive examination of employee health in the workplace. The more hazardous the exposure, the more in-depth the health evaluation should be. For example, hazardous waste workers should receive preplacement screening and periodic medical examinations, with testing for specific exposures as necessary. Table 15–F describes a recommended medical program. In work environments where respirator use is necessary, workers should be evaluated medically for fitness to wear a respirator. In most cases medical surveillance should include a medical and occupational history and a physical examination, with attention paid to the target organs and functions potentially affected. Medical records should be maintained to allow for review of deviations from the baseline of preplacement health status.

Biological exposure indices. The concept of biological monitoring has led the ACGIH to develop a list of biological exposure indices (BEIs®), published annually in their TLV® booklet. Similarly, OSHA has incorporated required biological monitoring into several standards (Table 15–E). Several of OSHA's standards (such as those for benzene and ethylene oxide) only require medical surveillance when air sampling has revealed a pattern of exposure above either the action level (AL) or PEL during a specific number of days per year. In 1988, OSHA published an advance notice of proposed rulemaking on medical surveillance programs. To date, no standard has been adopted.

NIOSH, in conjunction with state departments of health, has promoted the use of medical screening and biological sampling results to investigate occupational exposure and illnesses. Many states now have occupational lead registries that facilitate investigation of the number of workers poisoned by lead on the job and promote analyses of those industries most responsible. These results can be used to develop educational materials for small businesses needing assistance in controlling hazards, and in selecting sites for government intervention for public health purposes. For example, the Massachusetts Occupational Lead Registry found that 70 percent of their registrants with blood lead concentrations greater than 40 micrograms of lead per deciliter of blood worked in painting, deleading, and other construction jobs (Tumpowsky et al, 1998; Rabin et al, 1994). This discovery led to efforts to work with the state's highway department to more closely supervise bridge-painting contracts.

Combined effects. At present, very little is known about how the body integrates two different types of stress and the resultant strain, even if both stressors are chemical. The usual assumption is that chemicals affecting different organs or tissues should be considered independently, whereas those that affect the same organ or tissue should be considered jointly because they may produce additive or synergistic effects.

Synergism is known to occur with certain exposures. The best-known synergistic effect is that of smoking combined with asbestos exposure. The risk of lung cancer increases greatly, beyond that expected from adding the risks together. Similarly, in vitro studies of organophosphorus pesticides have shown that a combined exposure to malathion and Diazinon (dimpylate)

Table 15–E. ***OSHA Standards Requiring Medical Surveillance***

29 CFR	*Standard*
1910.95	Occupational Noise Exposure
1910.156	Fire Brigade
1910.134	Respiratory Protection
1910.120	Hazardous Waste Operations and Emergency Response standard (HAZWOPER)
1910.1001	Asbestos
1910.1003	13 Carcinogens (Exposure during emergency); individual chemicals also listed separately under 1910.1004-1016; medical surveillance referred back to 1910.1003
1910.1017	Vinyl chloride
1910.1018	Inorganic arsenic
1910.1025	Lead
1910.1027	Cadmium
1910.1028	Benzene
1910.1029	Coke oven emissions
1910.1030	Occupational Exposure to Bloodborne Pathogens
1910.1043	Cotton Dust
1910.1044	1,2-Dibromo-3-chloropropane
1910.1045	Acrylonitrile
1910.1047	Ethylene Oxide
1910.1048	Formaldehyde
1910.1050	Methylenedianiline
1910.1051	1,3-Butadiene
1910.1052	Methylene Chloride
1926: Construction Standards: The requirements applicable to construction work under these sections are identical to those set forth above, under 1910….	
1926.52	Occupational noise exposure
1926.62	Lead in Construction
1926.1101	Asbestos
1926.1103	13 Carcinogens (4-Nitrobiphenyl, etc.)
1926.1117	Vinyl chloride
1926.1118	Inorganic arsenic
1926.1127	Cadmium
1926.1128	Benzene
1926.1129	Coke Oven emissions
1926.1144	1,2-Dibromo-3-chloropropane
1926.1145	Acrylonitrile
1926.1147	Ethylene Oxide
1926.1148	Formaldehyde
1926.1152	Methylene Chloride
1928.1027 Agriculture Standards: The requirements applicableto agricultural work under this section are identical to thoseset forth above, under 1910…	Cadmium

Table 15–F. ***Recommended Medical Program***

Component	*Recommended*	*Optional*
Preplacement screening	Medical history. Occupational history. Physical examination. Determination of fitness to work while wearing protective equipment. Baseline monitoring for specific exposures.	Freezing preplacement serum specimen for later testing (limited to specific situations).
Periodic medical examinations	Yearly update of medical and occupational history; yearly physical examination; testing based on examination results, exposures, and job class and task. More frequent testing based on specific exposures.	Yearly testing with routine medical tests.
Emergency treatment	Provide emergency first aid on site. Develop liaison with local hospital and medical specialists. Arrange for decontamination of victims. Arrange in advance for transport of victims. Transfer medical records; give details of incident and medical history to next care provider.	
Nonemergency treatment	Develop mechanism for nonemergency health care.	
Record keeping and review	Maintain and provide access to medical records in accordance with OSHA and state regulations. Report and record occupational injuries and illnesses. Review site safety plan regularly to determine whether additional testing is needed. Review program periodically. Focus on current site hazards, exposures, and industrial hygiene standards.	

results in cholinesterase inhibition significantly greater than a mere summation of the effects would predict (Iyaniwura, 1990).

Other research has focused on less obvious combined effects. One study looked at the effects of different chemicals on hearing and found that trichloroethylene, arsenic, heavy metals, organo-tin compounds, and manganese all caused some degree of hearing loss or audiometric abnormalities in occupationally exposed workers. Carbon disulfide interacted with noise to cause sensorineural hearing loss; toluene and noise acted synergistically to increase the incidence of hearing loss (Ryback, 1992). Another study, looking at the combined effects of chemicals commonly found at hazardous waste sites, saw both synergistic and antagonistic interactions. Whereas lead tetraacetate and arsenic trioxide produced antagonistic effects in one assay, tetrachloroethylene and dieldrin produced synergistic effects. The authors of this genotoxicity study cautioned that compounds may behave differently in a mixture than when alone (Ma et al, 1992).

The OSHA airborne exposure limits, as well as the RELs and TLVs®, have been developed under the assumption that workers are exposed to chemicals one at a time. In fact, exposure to just a single chemical rarely occurs. One method to calculate the alteration in guidelines necessary to evaluate combined exposure is to add concentrations as a fraction of their respective TLVs. If the total equals or exceeds one, then an overexposure has been detected. This is not a conservative approach, because it assumes additive effects and allows excessive exposures if the effects are synergistic or if other stressors are present.

In most workplace exposure assessments, chemical, physical, biological, and psychological hazards are present at the same time. For example, the process of tunneling can involve simultaneous exposures to high atmospheric pressure, dust, noise, heat, high humidity, carbon monoxide, and physical safety hazards. An assessment of strain produced by any one of these stressors would be complicated by the presence of any or all of the others.

Limitations of biological monitoring. Biological monitoring is one way to compare exposure to dose. However, it must be remembered that it measures exposure only after it occurs, and after the contaminant has affected the body in some way. It must be used properly and in conjunction with other environmental controls and not as the sole control measure, as is sometimes the case when employers want to spare the cost of a more comprehensive, and therefore more expensive, monitoring program. Biological monitoring and

medical surveillance are not replacements for environmental or personal sampling but should be used to complement them.

When biological monitoring is required by an OSHA comprehensive standard, the health care provider conducting the monitoring must be given a copy of the requirements. In some cases, the medical personnel will want to tour the workplace to enhance their awareness of potential hazards. The California Department of Health has developed model language to ensure that employers and health care providers develop a contract that accurately reflects the expectations and needs of both parties. (California Occupational Health Program, 1990). It is available in a workbook developed for the radiator repair industry, and available from the California Occupational Health Program (COHP) Dept. of Health Services, 2151 Berkeley Way, Annex Eleven, Berkeley, California 94704.

Sampling

STRATEGY

The preliminary research and initial field survey help identify potential hazards to which workers may be exposed. The next task is to devise a sampling strategy to determine the intensity of exposure, the source of the hazards, and the adequacy of controls in place. Included in the plan must be a consideration of the sources of error, the desired precision and accuracy of measurements, and the degree of confidence needed for interpretation of the results.

If the industrial hygiene sampling is conducted to evaluate a problem, the sampling strategy can be designed to measure the "worst case." An example that occurred in central Massachusetts in 1990 illustrates this approach. Periodic use of a degreaser had resulted in dizziness and headaches in its two operators, as well as complaints from a neighboring department. Because the use of the degreaser was limited to three hours in the morning, it seemed unlikely that the eight-hour time-weighted average exposure exceeded the relevant PEL. However, the health symptoms and complaints indicated a problem with the operation of the degreaser, its cooling coils, or the local exhaust ventilation. Air sampling was planned to capture the particular solvent used during the worst-case exposure, when the smallest parts were being cleaned. Before sampling proceeded for this suspect carcinogen, the industrial hygienist made sure that the work practices and ventilation were exactly the same as they had been the day before, when the complaints had occurred.

Evaluating the worst case first, during the time of greatest exposure, at a location known to have caused problems, offers three advantages. First, this sampling is designed to solve a problem. Measuring the concentration of the chemical believed to have caused health symptoms and concerns helps identify the source, improve the controls, and correct the problem. Second, such results teach employees valuable lessons about indicators of equipment malfunction, the warning signs of overexposure, and the impact of work practices on airborne solvent levels, such as reducing drag-out of solvent. Finally, the process of evaluating the worst case during the longest exposure time to the highest expected concentration—if lower than the referenced PELs, STELs, TLVs®, and RELs—allows assumptions and assurances to be made regarding shorter-term, lower-level exposures.

Another approach to air sampling is to capture "typical" conditions. This is not always as easy as it sounds. Day-to-day variations may make a typical exposure difficult to define and measure. In addition, managers and employees being monitored may take extra precautions when they know they are being observed by health and safety professionals. Concerns about being "sampled" or evaluated may serve to encourage companies to present their best face by adding ventilation or opening doors and windows that are usually closed. Preliminary air sampling is usually done on the day shift, when supervision is better, shipping doors are more likely to be open, and the timer for the ventilation is on the occupied setting.

A good sampling strategy makes use of both worst-case and typical sampling methods, each selected to answer the questions what, where, when, how, and whom to sample.

WHAT AND HOW TO SAMPLE

The first and key principle to keep in mind is that samples should represent workers' exposures. Decisions about which chemicals to evaluate should be based on such factors as quantities and methods of use; worker reports of adverse experiences; concerns regarding high toxicity, volatility, carcinogenicity, or teratogenicity; and percent representation in mixtures.

For time-weighted average sampling, the *NIOSH Manual of Analytical Methods 1994* can be referred to for the correct sampling technique. There is a wide choice of collection media, from charcoal or silica gel tubes for organic nonpolar vapors or polar vapors, respectively, to cellulose ester or fiberglass filters for fumes and particulate materials. The appropriate medium for a specific reagent is stated in the NIOSH manual if there is an approved method. These are methods that have proved to be reproducible, given certain flow rates and sampling and analytical conditions.

Also available to the industrial hygienist are grab sampling methods, in which a specific release point is monitored at a specific time in the process. (See Figure 15–7.) This is done with colorimetric tubes (such as Draeger or Sensidyne tubes) or by "grabbing" a volume of air in a sampling bag, canister, or other container, which is then analyzed in an accredited laboratory. The colorimetric tube method has limitations in its accuracy and should be used only as an initial, rough exposure estimate. The sampling bag method has limitations in collection efficiency and should be performed under the guidance of a laboratory accredited by the American Industrial Hygiene Association (AIHA).

Figure 15–7. The gas detector tubes shown here are useful for obtaining direct readings of gas or vapor contamination in the workplace air.

Direct-reading instruments are available for a number of different chemical, physical, and radiation hazards (Figure 15–8). They provide immediate information about current conditions or concentrations, and can therefore be used to locate a source or detect a leak. Given this instant feedback, changes can be made in operating conditions, and the worksite can be evaluated for improvement. For example, it might be possible to alter ventilation settings and observe the impact on airborne hazard levels, or turn off a compressor and note a drop in noise levels.

Materials that are not listed in the NIOSH manual are more difficult to evaluate, and an accredited analytical laboratory should be consulted. All samples taken should be sent to an accredited analytical laboratory, and results will be reported back at a later date.

WHERE TO SAMPLE

Personal monitoring is used to evaluate actual exposures to an individual by sampling for specific agents in the worker's immediate vicinity for durations corresponding to the process of concern or the appropriate occupational exposure limit (such as TWA, STEL, or ceiling). The sampling device is attached directly to the employee and is worn throughout the sampling period, reflecting worker movements in relation to the source of contamination, during both work and rest periods. The results from personal monitoring should be used to determine the effectiveness of control measures (engineering, work practices, and administrative) implemented to prevent overexposure.

Area monitoring is used to measure the contaminants found in the work area that is generally occupied by employees. Also

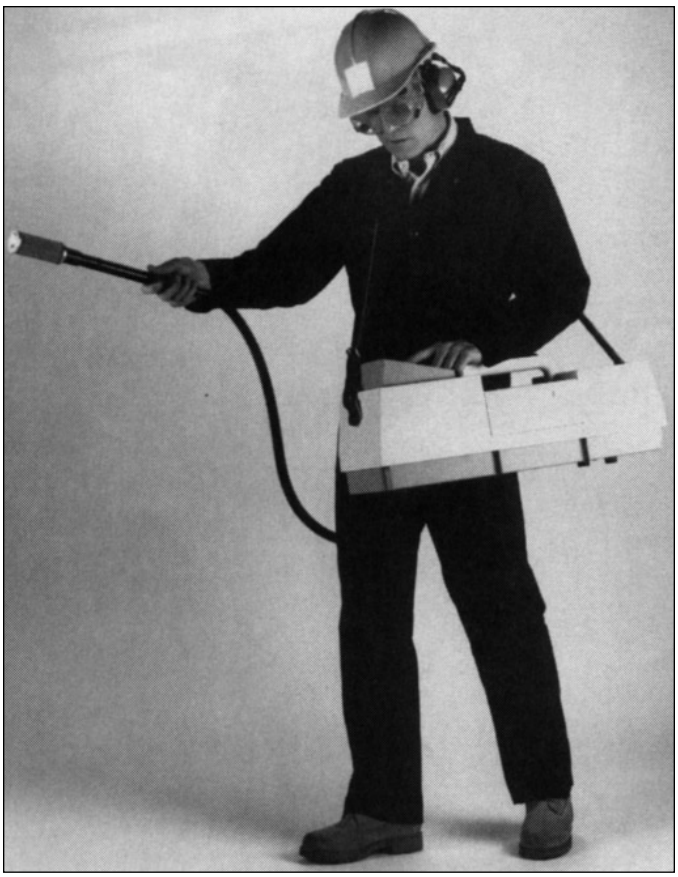

Figure 15–8. This portable ambient air analyzer can be used to measure concentrations at the operator's workstation. (Courtesy Foxboro Co.).

called environmental monitoring, it provides information about the amount and type of exposures found in a fixed area of interest. It reflects the effectiveness of engineering controls put into place to control the release of hazardous materials. It only reflects actual employee exposure to the extent that the time period monitored represents the time most employees spend in a given area.

Monitoring conducted for the purpose of measuring employee exposure is normally done with personal sampling. The recommended sampling method or equipment may, however, be inconvenient to use. If the industrial hygienist wishes to determine what air concentrations are in an area where the highest levels of contaminant release are anticipated, or where continuous exposure close to a particular point source may occur, then area monitoring is often useful. If results from these types of "worst-case" exposures are less than the upper regulatory or recommended limits, and if the contaminant in question is released only in that area, then an assumption can usually be made that workers spending their day in this area have exposures below the acceptable upper limit. This type of assumption is frequently made.

WHOM TO SAMPLE

If the initial determination indicates the possibility of excessive exposure to airborne concentrations of a toxic substance, measurements of the most highly exposed employee should be made. This can be determined by observing the point of release and selecting the employee who is closest to the source of the contaminant in question.

Air movement patterns within a workroom must be considered when evaluating potential exposures to workers. Especially in operations or processes involving heating or combustion, the natural air circulation could be such that the maximum-risk employee might be located at considerable distance from the source. The location of ventilation booths, air supply inlets, and open doors and windows and the size and shape of the work area are all factors that affect workroom airflow patterns and can produce elevated concentrations at locations far removed from the source.

Differences in work habits of individual workers can significantly affect levels of exposure. Even though several workers are performing essentially the same tasks with the same materials, their individual methods of performing their work could affect the contaminant concentration to which each is exposed. Initial monitoring is often limited to a representative sample of the exposed population, usually those considered at greatest risk. Exposure results over the action level or PEL indicate that more extensive sampling is needed.

WHEN TO SAMPLE

Another factor that must be considered is when to sample. If temperature varies greatly from season to season, with windows kept open during one season and not another, then sampling should be done during both periods. Or, in this case, because more dilution of the contaminant occurs with windows open, worst-case exposure monitoring should be done with the windows closed. If air conditioning is used, levels of contaminant may be fairly constant throughout the year. However, this is not necessarily the case with variable air volume (VAV) systems that restrict fresh airflow during the coldest and hottest periods of the year. (See Chapter 21, General Ventilation of Nonindustrial Occupancies, for further discussion.) If the facility has more than one workshift, samples should be collected during each shift. Concentrations can vary considerably from time to time during the day, because of such factors as differences in production rate, degree of supervision, and ventilation provided during off-peak shifts.

HOW LONG TO SAMPLE

The volume of air sampled and the duration of sampling is based on the sensitivity of the analytical procedure or direct-reading instrument, the estimated air concentration, and the OSHA standard or the TLV® for that particular agent. Again, the *NIOSH Manual of Analytical Methods* or an accredited analytical laboratory should be consulted.

The duration of the sampling period should represent some identifiable period of time; for example, a complete cycle of an operation or a full shift. Often, the appropriate time period is specified in the regulatory upper limits when looking at a PEL, a full eight-hour shift of monitoring is

called for. For comparison to an OSHA short-term exposure limit (STEL), 15-minute samples during a worst-case exposure scenario are required. Longer workshifts require recalculation of the relevant standard, because the total time exposed is increased. For example, a 10-hour workshift requires that the PEL or TLV® be modified to reflect the extra exposure time and be reduced to four-fifths of the original eight-hour standard. To illustrate this point, OSHA's lead standard, in which the eight-hour TWA is 50 $\mu g/m^3$, requires employers to calculate the permissible exposure limit for workers exposed to lead for more than eight hours in any workday, using the following formula: Maximum permissible limit (in $\mu g/m^3$) = 400/hours worked in a day.

The concentration of contaminant in the workplace is sometimes low. Direct-reading instruments and other devices used to collect samples for subsequent analysis must collect a sufficient quantity of the sample so that the chemist doing the analysis can accurately determine the presence of minute amounts (parts per million or sometimes parts per billion) of the contaminant.

WHAT TO NOTE DURING SAMPLING

Accurate record keeping is essential for the correct interpretation of air-sampling results. The fundamental records include total time sampled; pump flow rate, both at the beginning and end of the sampling period; location of the area or identification of the person being monitored; and a description of the process being evaluated. In addition, sampling notes should include the engineering controls present and the location of any local or general exhaust ventilation, as well as any measurements of these taken at the time of sampling. If other processes are located close enough to affect the sampling results, they should be described.

Use of personal protective equipment should be documented. Observations of work practices can help explain differences between results for workers performing the same task. An air-sampling worksheet can be developed to help prompt such notes (see Figure 15–9).

HOW MANY SAMPLES TO TAKE

There is no predetermined number of samples that must be taken in order to adequately evaluate a worker's exposure. The number of samples to be taken depends on the purpose of the sampling, the number of different tasks a worker performs in a given day, and the variability inherent in the contaminant generation process.

There are guidelines in *The Occupational Exposure Sampling Strategy Manual* (U.S. DHEW, NIOSH, 1977) that can help in this decision-making process. They direct the industrial hygienist to ask pertinent questions such as whether the PEL or STEL is to be considered a ceiling value, not to be exceeded in any workday. Then, if this is the case, three nonrandom, worst-case exposure periods should be sampled. And if none of the results exceeds the PEL or STEL, one can be personally confident that they are not normally exceeded. However, one cannot be statistically confident of these results because the sampling periods were not randomly chosen. Without this random selection, a confidence limit for a worst-case exposure estimate cannot be computed because the results are not statistically representative of the entire exposed group.

WHEN TO STOP MONITORING

For the chemicals it regulates, OSHA requires that monitoring be conducted on a routine basis; the frequency depends on the substance and the results from the initial or most recent monitoring. For example, monitoring for formaldehyde can be terminated if results from two consecutive sampling periods, taken at least 7 days apart, show that employee exposure is below both the action level and the STEL. Any change in process or engineering controls requires additional sampling to assess the effects of the change.

If initial sampling results are low, it is not necessary to repeat routine monitoring of employee exposure, as long as monitoring of other factors crucial to the overall health and safety program continues. Areas of interest should include the adequacy of engineering controls, work practices; the use of personal protective equipment, and training in all of these aspects. Documentation of this oversight should be part of any effective health and safety management program. This continued monitoring also serves to meet the requirements of many OSHA standards, including the Hazard Communication Standard (29 *CFR* 1910.1200), Occupational Exposure to Hazardous Chemicals in Laboratories (29 *CFR* 1910.1450), the Respirator Standard (29 *CFR* 1910.134), and other, more specific ones that may apply to a given workplace.

WHO SHOULD CONDUCT SAMPLING

Although the concept of air sampling and the use of air-monitoring devices may at first appear to be simple, there are many considerations that must be balanced when devising a sampling strategy and interpreting the results, and it is often previous experiences that allow a final judgment to be made. It is therefore crucial that those conducting the sampling be adequately trained and supervised by a professional industrial hygienist. They must be cognizant of the potential for error and ensure proper calibration, maintenance, and use of sampling equipment. They must be familiar with potential problems and be available to resolve them if they occur. They must be aware of the limitations of sampling alone, know how to integrate observation and interviews with quantitative measurements, and know when it is not necessary to sample. The initial sampling strategy may lead to further questions or contradictions and significantly alter the overall plan. A comprehensive evaluation of the workplace depends on the judgment of the industrial hygienist.

Air Sampling Worksheet

Sample ID	Employee/Job Description	Flow Rate (Start/Stop)	Time (Start/Stop)	Total time (min)

Process Description:

Engineering Controls:

Work Practice Controls:

Ventilation Measurements:

Personal Protective Equipment Used:

Worker Comments:

Figure 15–9. Example of an air-sampling worksheet. (Printed with permission from Nancy Corneau, Massachusetts Division Occupational Hygiene.)

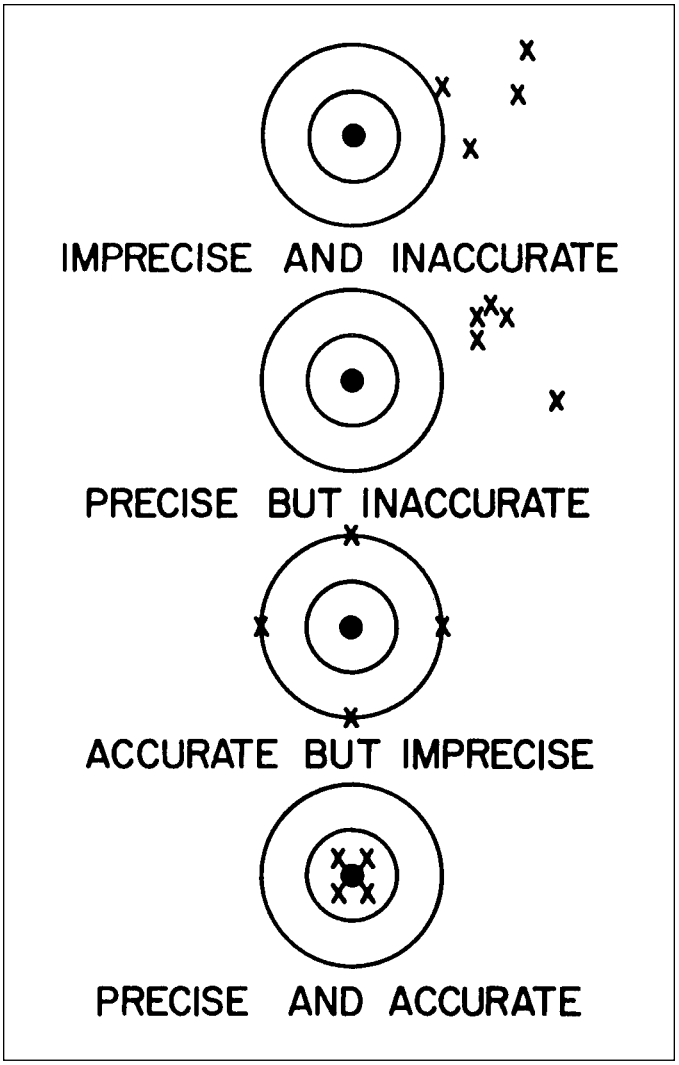

Figure 15–10. It is possible for a measurement to be precise but not accurate, and vice versa. (Reprinted with permission from Powell CH, Hosey AD, eds. *The Industrial Environment—Its Evaluation and Control*, 2nd ed. U.S. Public Health Services Pub No. 614, 1965.)

The title *Certified Industrial Hygienist* (CIH) indicates that the professional has at least five years' experience in the field of industrial hygiene, is currently in active practice, has met certain educational requirements, and has passed the series of professional exams required by the American Board of Industrial Hygiene (ABIH). Certification rosters are maintained by the ABIH. Membership in other professional organizations, such as the AIHA and ACGIH, indicates active participation in the current field of industrial hygiene but does not guarantee the CIH title. Both the AIHA and ACGIH maintain rosters of their members.

REQUIRED ACCURACY AND PRECISION

Although the word *sampling* is commonly used, its full implications are not always realized. To sample means to measure only part of the environment, and, from the measurements taken, infer conclusions about the whole. In all sampling methods, there are both systematic and random errors to consider that can affect the interpretation of results and, therefore, final judgment about the work environment as a whole. Any exposure average calculated from air-sampling measurements is only an estimate of the true exposure. It is important to recognize, preferably in advance, where possible sources of error lie; to eliminate or control them to the degree possible; and to account for them in the interpretation of results.

Accuracy. Accuracy concerns the relationship between a measured value and the true value. For a measurement to he accurate, it must be close to the true value.

Precision. Precision is the degree of agreement among results obtained by repeated measurements under the same conditions and under a given set of parameters. It is possible for a measurement to be precise but not accurate, and vice versa (Figure 15–10).

Accuracy is affected by controllable sources of error. These are called determinate or systematic errors and include method error, personal error, and instrument error. Incorrect calculations, personal carelessness, poorly calibrated equipment, and use of contaminated reagents are examples of systematic error. They contribute a consistent bias to the results that renders them inaccurate. Where possible, these must be identified before sampling is performed, and eliminated or controlled.

Precision is affected by indeterminate or random errors, which cannot be controlled. These include intra- or inter-day concentration fluctuations, sampling equipment variations such as random pump flow fluctuations, and analytical method fluctuations such as variation in reagent addition or instrument response. These factors cause variability among the sample results. Statistical techniques are used to account for random error. For example, increasing the number of samples taken minimizes the effect of random error.

In several of the OSHA substance-specific standards, accuracy ranges for the sampling methods are specified for both the PEL and the STEL. For example, the Ethylene Oxide Standard (29 *CFR* 1910.1047) requires that a sampling method with accuracy to a confidence level of 95 percent (within 25 percent) be obtained for airborne concentrations of ethylene oxide at the 1.0 ppm PEL and within 35 percent at the action level of 0.5 ppm.

In order to ensure accuracy and precision, the following guidelines should be used:

- ➢ Manufacturers' data for direct-reading instruments should be obtained whenever possible, stating the accuracy and precision of their method.
- ➢ A calibration schedule should be established and documented for all sampling equipment.
- ➢ The *NIOSH Manual of Analytical Methods* should be consulted for accuracy and precision of the methods chosen. When reporting the results of the sampling, the NIOSH sampling method followed should be cited.

➢ Only laboratories that participate in industrial hygiene quality control programs, such as the one conducted by the AIHA, should be used.

In addition, to ensure compliance or violation, OSHA compliance officers use one-sided confidence limits (upper and lower confidence limits, UCL and LCL) whenever sampling is performed (OSHA Technical Manual, 1991, Appendix 1–F). This practice recognizes that the sample measured on the employee is rarely the same as the "true" exposure, because of sampling and analytical errors (SAEs). The UCL and LCL incorporate these error factors statistically in order to obtain the lowest (LCL) and the highest (UCL) value that the true exposure could be, within a 95 percent confidence interval. The UCL and LCL are called one-sided limits because they are used by both OSHA and employers to ensure that the true exposure lies on one side of the OSHA permissible exposure limit (PEL), either above or below it.

For example, if neither the measured results nor its UCL exceed the PEL, then one can be 95 percent confident that the exposure does not exceed the PEL. On the other hand, if both the measured exposure and its LCL exceed the PEL, then one can be 95 percent confident that the exposure exceeds the PEL, and a violation is established. Also listed in Appendix 1–F are grayer areas of evaluation; for example, when the UCL of an exposure exceeds the PEL but the measured exposure does not. OSHA offers guidance in these instances, including suggesting that further monitoring be conducted.

In order to compute the UCL and the LCL, the coefficient of variation (CV) for each analytical method must be computed. These can also be found in the *NIOSH Manual of Analytical Methods*.

$$\mathrm{CV} = 100\frac{\mathrm{sd}}{m} \tag{1}$$

where sd = standard deviation of the method
m = mean (or analytical result)
100= factor to convert from fraction to percent

SAEs are often listed in OSHA report forms, but can he derived from the $\mathrm{CV_{total}}$:

$$\mathrm{SAE} = 1.645(\mathrm{CV_{total}}) \tag{2}$$

where $\mathrm{CV_{total}}$ = the coefficient of variation of the sampling method plus the coefficient of variation of the analytical method.

In general, the formula for the LCL at the 95th percentile level is

$$\mathrm{LCL\,(95\%)} = \frac{x_{\mathrm{mean}}}{\mathrm{PEL}} - 1.645\frac{\mathrm{CV_{total}}}{\sqrt{n}} \tag{3}$$

where LCL (95%) = lower confidence limit at the 95th percentile
x_{mean} = average airborne concentration
$\mathrm{CV_{total}}$ = coefficient of variation including sampling error
n = number of data points to determine x_{mean}
1.645 = appropriate factor from large sample statistics

In a similar fashion, the general formula for the UCL at the 95th percentile level is

$$\mathrm{UCL\,(95\%)} = \frac{x_{\mathrm{mean}}}{\mathrm{PEL}} + 1.645\frac{\mathrm{CV_{total}}}{\sqrt{n}} \tag{4}$$

OSHA uses simplified versions of the above formulas and distinguishes between three types of samples: full-period, continuous single samples; full-period consecutive samples; and grab samples. For a complete discussion of the calculations, refer to Appendix 1–F of the *OSHA Technical Manual*.

Example

A charcoal tube and personal sampling pump were used to sample for xylene for an 8-hour period. The laboratory reported results of 105 ppm of xylene. The PEL for xylene is 100 ppm. The SAE for the sampling and analytical method is 0.10.

Solution

The steps required to calculate the UCL and the LCL for this full-period, single sample are as follows:

1. Determine the standardized concentration, Y:

$$Y = \frac{X}{\mathrm{PEL}} \tag{5}$$

where X is the full-period sampling result. Therefore, for our example,

$$Y = \frac{105}{100} = 1.05 \tag{6}$$

2. Compute the UCL (95%) and the LCL (95%):

$$\mathrm{UCL\,(95\%)} = Y + \mathrm{SAE} \tag{7}$$

$$\mathrm{LCL\,(95\%)} = Y - \mathrm{SAE} \tag{8}$$

Therefore, for our example,

$$\mathrm{UCL} = 1.05 + 0.10 = 1.15 \tag{9}$$

$$\mathrm{LCL} = 1.05 - 0.10 = 0.95 \tag{10}$$

3. When the UCL ≤ 1 a violation does not exist, according to OSHA. When the LCL > 1 a violation exists, according to OSHA. If the LCL ≤ 1 and UCL > 1, the result is classified as a possible overexposure. In our example, because the LCL ≤ 1 and the UCL > 1, a possible overexposure exists.

INDUSTRIAL HYGIENE CALCULATIONS

Gases and Vapors

Calculations for gas and vapor concentrations are based on the gas laws. Briefly, these are as follows:

- ➢ The volume of gas under constant temperature is inversely proportional to the pressure: $P_1V_1 = P_2V_2$
- ➢ The volume of gas under constant pressure is directly proportional to the Kelvin temperature, which is based on absolute zero (0 C = 273 K). The Rankine temperature scale is also used, where 0 C = 492 R, or degrees R = degrees F + 460.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \tag{11}$$

- ➢ The pressure of a gas of a constant volume is directly proportional to the Kelvin (or Rankine) temperature:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \tag{12}$$

and $PV = nRT$.

Thus, when measuring contaminant concentrations, it is necessary to know the atmospheric temperature and pressure under which the samples were taken. At standard temperature (0 C) and pressure (760 mmHg) (STP), 1 g-mol of an ideal gas occupies 22.4 liters. If the temperature is increased to 25 C (normal room temperature) and the pressure is the same, then 1 g-mol occupies 24.45 liters.

$$(22.4 \text{ liters})\frac{273 + 25}{273} = 24.45 \tag{13}$$

The concentration of gases and vapors is usually expressed in parts of contaminant per million parts of air, or parts per million (ppm).

$$\text{ppm} = \frac{\text{Parts of contaminant}}{\text{Million parts of air}} \tag{14}$$

This is a volume-to-volume relationship. Equivalent parts per million expressions include

$$\frac{\text{liters}}{10^6 \text{ liters}} = \frac{\text{centimeter}^3}{10^6 \text{ centimeter}^3} = \frac{10^{-3}\text{ L}}{10^3\text{ L}} = \frac{\text{milliliters}}{\text{meter}^3} = \frac{\text{feet}^3}{10^6 \text{ feet}^3} \tag{15}$$

Sometimes it is necessary to convert milligrams per cubic meter (mg/m^3), a weight-per-unit volume ratio, into a volume-per-volume ratio. To begin, milligrams per cubic meter must be converted to millimoles per cubic meter and to milliliters per cubic meter, or parts per million. It is helpful in making this conversion to use dimensional analysis.

$$\left(\frac{\text{mg}_x}{\text{m}^3 \text{ air}}\right)\left(\frac{\text{mmol}_x}{\text{mg}_x}\right)\left(\frac{24.45\,\text{mL}_x}{\text{mmol}_x}\right) = \frac{\text{mL}_x}{\text{m}^3 \text{ air}} = \text{ppm} \tag{16}$$

At room temperature, to convert from ppm to mg/m^3, a similar conversion can be performed:

$$\frac{\text{mg}}{\text{m}^3} = \frac{\text{molecular weight}}{24.45 \text{ at } 25\text{ C}}\text{ppm} \tag{17}$$

Another method to predict gas or vapor concentration in parts per million is the partial pressure method. By dividing the vapor pressure of the material in question by the barometric pressure, the resultant percent fraction can then be multiplied by one million (10^6) in order to give a volume percent in ppm.

$$\frac{\text{vapor pressure of one constituent}}{\text{total barometric pressure}}10^6 \tag{18}$$

$$= \text{ppm of constituent}$$

Example

Given the concentration of a vapor at STP in grams per liter, convert this to parts per million (ppm).

Solution

Given that the gram-molecular volume at STP (0C and 760 mmHg) is 22.4 L, and that molecular weight is g/mol, the concentration of vapor at STP is

$$\frac{\text{grams of vapor}}{\text{liters of vapor}} = \left(\frac{\text{g}}{\text{mole}}\right)\left(\frac{\text{mole}}{\text{L}}\right) = \frac{\text{molecular wt (g)}}{22.4\text{(L)}} \tag{19}$$

Rearranging terms,

$$\text{liters of vapor} = \frac{(\text{grams of vapor})(22.4)}{\text{molecular wt}} \tag{20}$$

$$\text{ppm} = \frac{\text{parts of vapor}}{\text{1,000,000 parts of air}} = \frac{\text{liters of vapor}}{10^6\text{ L of air}} \tag{21}$$

Substituting liters of vapor from Equation 21 into Equation 22,

$$\text{ppm} = \frac{\dfrac{(\text{grams of vapor})(22.4)}{\text{molecular wt (g)}}}{10^6 \text{ L of air}}$$

$$= \frac{\dfrac{(10^3 \text{ mg of vapor})(22.4)}{\text{molecular wt (g)}}}{10^6 \text{ L}} \qquad (22)$$

Given that 10^6 L = 10^3 m^3,

$$\text{ppm} = \frac{(10^3 \text{ mg})(22.4)}{(10^3 \text{ m}^3)(\text{molecular wt of vapor})}$$

$$= \left(\frac{\text{mg}}{\text{m}^3}\right)\frac{22.4}{\text{molecular wt}} \qquad (23)$$

For some chemicals, the analytical method requires the collection of material into a fixed volume of absorbing or reacting solution. The laboratory to which the sample is sent first analyzes the concentration of contaminant in the collection medium, then multiplies the volume of solution by the contaminant concentration and reports the total amount of contaminant collected during the sampling period. This can be converted to air concentration by dividing the total amount of contaminant sampled by the total amount of air collected.

Example

At 25C and 755 mmHg, 15L of air is bubbled through 30 mL of a solution that has 100 percent collection efficiency for HCl (molecular weight = 36.5). The analytical laboratory reports the solution concentration as 15 mg/mL. What is the air concentration of HCl in ppm?

Solution

First, the total amount of HCl is

$$\frac{15 \text{ µg}}{\text{mL}}(30\text{mL}) = 450 \text{ µg} \qquad (24)$$

Correcting for temperature and pressure in micromoles (µmol), the volume of 1 µmol of HCl is as follows:

$$1 \text{ µmol} \times 22.4 \times \frac{298}{273} \times \frac{760}{755} = 24.6 \text{ µL} \qquad (25)$$

Finally, the air concentration sampled in ppm is

$$\frac{450 \text{ µg HCl}}{15 \text{ L of air}} \times \frac{\text{µmol HCl}}{36.5 \text{ µg HCl}} \times \frac{24.6 \text{ µl HCl}}{\text{µmol HCl}}$$

$$= \frac{11{,}070 \text{ µL HCl}}{547.5 \text{ L of air}} = 20.22 \text{ ppm} \qquad (26)$$

Another useful equation to derive is the vapor concentration of a given amount of material in a chamber or a room, given the following:

V_T = chamber volume in liters
MW = molecular weight of a substance, in g/mol
T = absolute temperature in degrees Kelvin (K = C+273)
P = pressure in mmHg
ρ = density, in g/mL
V_X = volume of material in chamber or room, in mL
C = concentration, in ppm

To find liters of pure vapor

$$\frac{(V_x\text{mL})(\rho)(22.4 \text{ L/mol})}{\text{molecular wt of material}}\left(\frac{T}{273}\right)\left(\frac{760}{P}\right) \qquad (27)$$

$$C = \left(\frac{\text{liters of pure vapor}}{V_T}\right)10^6 \text{ parts of air}$$

$$= \frac{(V_x)(\rho)\left(\dfrac{22.4 \text{ L}}{\text{g-mol}}\right)\left(\dfrac{\text{g-mol}}{\text{MW}}\right)\left(\dfrac{T}{273}\right)\left(\dfrac{760}{P}\right)}{V_T 1} \times 10^6$$

$$= \frac{(V_x)(\rho)\left(\dfrac{22.4}{\text{MW}}\right)\left(\dfrac{T}{273}\right)\left(\dfrac{760}{P}\right)}{V_T} \times 10^6 \qquad (28)$$

One can also calculate the volume of liquid necessary to produce a desired concentration in a given volume at room temperature and standard pressure:

$$V_x = \frac{C \times \text{MW} \times 273 \times P \times V_T}{\rho \times 22.4 \times T \times 760 \times 10^6} \qquad (29)$$

Example

How much acetone (MW=58.08 g/mol; density = 0.7899 g/mL) is needed to generate a concentration of 200 ppm in a 20-L container at 25°C and 740 mmHg?

Solution

$$V_x = \frac{(200)(58.08)(273)(740)(20)}{(0.7899)(22.4)(298)(760)} \times \frac{1}{10^6}$$

$$= 0.012 \text{ mL} \qquad (30)$$

Vapor Equivalents

When a liquid is released into a space of known dimensions, it is useful to determine the volume it will occupy when evaluating potential exposures from this release. The following formula is often helpful, because it establishes the amount of pure vapor formed at sea level by the complete evaporation of a known volume or weight of a liquid into an area, based on the following assumptions:

liters/mole of vapor at STP = 22.4
grams/pound = 453.6
liters/cubic foot = 28.32

grams/gram-mole = MW

$$\frac{\text{cubic feet of vapor}}{\text{pound of liquid}} = \left(\frac{\text{ft}^3}{\text{L}}\right)\left(\frac{\text{L}}{\text{mol}}\right)\left(\frac{\text{mol}}{\text{g}}\right)\left(\frac{\text{g}}{\text{lb}}\right)$$

$$= \left(\frac{1\ \text{ft}^3}{28.3\ \text{L}}\right)\left(\frac{22.4\ \text{L}}{\text{mol}}\right)\left(\frac{\text{mol}}{\text{g-MW}}\right)\left(\frac{453.6\ \text{g}}{\text{lb}}\right) = \frac{359}{\text{MW}} \qquad (31)$$

This can be calculated for different temperatures and pressures.

Example
At 70 F, what volume would one pound of toluene (MW = 92) occupy?

$$\frac{\text{cubic feet}}{\text{pound}} \text{ at } 70\text{ F} = \frac{(530\text{ R})(359)}{(492\text{ R})(\text{mol wt})}$$

$$= \frac{387}{92} = 4.163\ \text{ft}^3 \qquad (32)$$

Solution
Note that the Rankine scale was used here, and that R = F + 460. Therefore, 70 F =530 R, and 0 C=32 F = 492 R. However, it must be noted that quantities of liquids are often stated as volumes, for example in pints or liters, and that, in order to use equation (31), liters or pints must first be converted into pounds.

Example
A 1-pint container of toluene breaks in a room 50 feet by 100 feet by 15 feet. Assuming complete evaporation and no ventilation, what would you expect the concentration of toluene to be in the room, assuming the following:

T= 70 F
mass of water = 1.041 pounds/pint
specific gravity (sp gr) of toluene = 0.866 (the ratio of the mass of toluene to the mass of water at that temperature)

$$\left(\frac{\text{cubic feet}}{\text{pound}}\right)\left(\frac{\text{pound}}{\text{pint}}\right) = \frac{\text{cubic feet}}{\text{pint}} \qquad (33)$$

$$= \frac{(387)(1.041)(\text{sp gr})}{\text{molecular wt}} = \frac{(403)(0.866)}{92} = 3.79\ \text{ft}^3$$

and the room volume is (50 ft)(100 ft)(15 ft) = 75,000 ft^3. The concentration is then

$$\frac{3.79\ \text{cubic feet of toluene}}{75{,}000\ \text{cubic feet air}} \times 10^6 = 50.53\ \text{ppm} \qquad (34)$$

Example
A half-pound cylinder of chlorine fell and broke in a closed room 60 feet by 45 feet by 15 feet. What is the concentration of chlorine in ppm?

Solution
The room volume is

$$(60\text{ ft})(45\text{ ft})(15\text{ ft})\left(\frac{1\ \text{m}^3}{35.31\ \text{ft}^3}\right) = 1{,}147\ \text{m}^3 \qquad (35)$$

Therefore, the concentration of chlorine in the room is

$$(0.5\text{ lb Cl}_2)\left(453.6\frac{\text{g}}{\text{lb}}\right)\left(\frac{\text{mol}}{71\text{ g}}\right)\left(\frac{24.45\text{ L}}{\text{mol}}\right)$$

$$\left(\frac{\text{m}^3}{10^3\text{ L}}\right)\left(\frac{1}{1{,}147\ \text{m}^3}\right) \times 10^6 = 68.2\ \text{ppm} \qquad (36)$$

Weight-per-Unit Volume

When a contaminant is released into the atmosphere as a solid or liquid and not as a vapor—for example as a dust, mist, or fume—its concentration is usually expressed as a weight per volume. Outdoor air pollutants and stack effluents are usually expressed in grams, milligrams, or micrograms per cubic meter of air (g, mg, or μg/m^3), ounces per thousand cubic feet (oz/1,000 ft^3), pounds per thousand pounds of air (lb/1,000 lb), or as grains per cubic foot (gcf).

Time-Weighted Average (TWA) Exposure

The time-weighted average exposure evolved as a method to calculate daily or full-shift average exposures, given that employees' job tasks may vary during a day and that facility operating conditions may also vary. In typical work environments, workers may experience several different, short-term exposures to the same material. By taking a time-weighted average of these exposures, the industrial hygienist can estimate or integrate the short-term measurements into an eight-hour exposure estimate and compare this to the relevant health and safety regulations or information. The TWA is determined by the following formula, where

C = concentration of the contaminant
T = time period during which this concentration was measured

$$\text{TWA} = \frac{C_1T_1 + C_2T_2 + C_nT_n}{8\text{ hrs}} \qquad (37)$$

The TWA is usually expressed in ppm or in mg/m^3. Because OSHA's PELs and the ACGIH's TLVs® are both based on an eight-hour workday, the denominator in this formula is usually eight hours. However, any TWA can be determined, using the following formula:

$$\frac{\sum_{i=1}^{n} (T_i)(C_i)}{T_{\text{total}}\text{ work time}} = \text{TWA} \qquad (38)$$

where i is an increment of time and C is the concentration measured during that time. In this way, sequential incremental

measurements can be made, allowing analysis of short-term exposures at the same time as a longer TWA is being computed. The total time covered by the samples should be as close to the total exposure time as possible.

Example
A TWA of a foundry worker's exposure to particulates can be evaluated by the following series of short-term samples:

Sample Number	*Time*
1	7:00 a.m. to 8:00 a.m.
2	8:00 a.m. to 9:30 a.m.
3	9:30 a.m. to 11:00 a.m.
4	11:00 a.m. to 1:00 p.m. (turned off and covered during 30-min lunch)
5	1:00 p.m. to 3:30 p.m.

The measurement obtained is a full-period consecutive-sample measurement because it covers the entire time period applicable to the PEL or TLV®.

In some cases, because of limitations in measurement methodology—for example, direct-reading instruments or charcoal tubes—it is impossible to collect consecutive samples whose total sampling duration equals that of the required time period stated in the relevant standard. In these cases, the grab methods are used for time periods that are felt to be representative of the entire workshift.

Example
It is necessary to use charcoal tubes to estimate an employee's exposure to chloroform. Each charcoal tube is limited to 60 minutes' collection time. Out of the possible eight samples that could have been taken, only six were collected. The following results were obtained:

Sample Number	*Results (ppm)*
1	55
2	65
3	55
4	60
5	45
6	60

Solution
The six-hour TWA for these exposures is

$$\frac{1}{360\ \text{min}}[(60\ \text{min})(55\ \text{ppm}) + (60)(65) + (60)(55) + (60)(60) + (60)(45) + (60)(60)] = 57\ \text{ppm} \quad (39)$$

If there is not much variation in the levels of air contamination measured, and it is certain that the employee's entire workday is spent in one area, then it is probably acceptable to assume that this represents an eight-hour TWA. If there is significant variation, however, resampling should be done for the entire eight-hour day.

Example
An employee spends four hours of an eight-hour shift in an area where measured CO air concentrations remain fairly constant at 50 ppm. For the remaining four hours, the employee works in an area where there is no measurable CO in the air. What is the employee's eight-hour TWA?

Solution

$$\frac{(4\ \text{h})(50\ \text{ppm}) + (4\ \text{h})(0\ \text{ppm})}{8\ \text{h}} = \frac{200\ \text{ppm} \bullet \text{h}}{8\ \text{h}} = 25\ \text{ppm} \quad (40)$$

Example
A machinist works from 7:00 a.m. to 4:00 p.m. tending an automatic screw machine. The following levels of oil mist were measured:

Time	*Average Level of Oil Mist (mg/m^3)*	*Time*	*Average Level of Oil Mist (mg/m^3)*
7:00-8:00	0	11:00-12:00	2.0
8:00-9:00	1.0	12:00-1:00	0.0*
9:00-10:00	1.5	1:00-3:00	4.0
10:00-11:00	1.5	3:00-4:00	5.0

* lunch period, no exposure

Solution
The TWA of the machinist's exposure to oil mist is calculated as follows:

$$\frac{\sum_{i=1}^{i=8} (T_i)(C_i)}{T_{\text{total}} = 8\ \text{h}} = \text{TWA} \quad (41)$$

Time (h) x Concentration (mg/m^3)		
(1)	(0)	=0
(1)	(1)	=1
(1)	(1.5)	=1.5
(1)	(1.5)	=1.5
(1)	(2.0)	=2.0
(1)*	(0.0)	=0.0
(2)	(4.0)	=8.0
(1)	(5.0)	=5.0
		19.0 (h)(mg/m^3)

$$\frac{\sum_{i=1}^{i=8} (T_i)(C_i) = (19.0\ \text{h})(\text{mg}/\text{m}^3)}{8\ \text{h}} = 2.38\ \text{mg}/\text{m}^3 \quad (42)$$

Example
An employee is exposed to an average level of 100 ppm of xylene for 10 minutes out of every hour; during the remaining 50 minutes of each hour, there is no exposure to xylene. What is the TWA for xylene for this employee?

Solution
Because there are eight hours in a workday, each of which includes 10 minutes' exposure to 100 ppm and 50 minutes' exposure to 0 ppm, an eight-h TWA can be calculated as follows:

$$\frac{(8)\ (10\ \text{min})\ (100\ \text{ppm}) + (8)\ (50\ \text{min})\ (0\ \text{ppm})}{480\ \text{min}}$$
$$= \frac{8{,}000\ \text{min} \cdot \text{ppm}}{480\ \text{min}} = 16.7 = 17\ \text{ppm} \qquad (43)$$

Example
An employee is exposed to the same material at two work locations during an 8-hour shift. Monitoring of this worker's exposure was conducted by taking grab samples at each of the locations. The following results were obtained:

Operation	*Duration*	*Sample*	*Results (ppm) (5-min sample)*
Cleaning room	8:00-11:30 a.m.	A	150
		B	120
		C	190
		D	170
		E	210
Print shop	12:30-4:30 p.m.	F	90
		G	70
		H	120
		I	110

Solution
The average exposure (C_2) in the cleaning room:

$$C_i = \frac{120 + 150 + 170 + 190 + 210}{5} = 168\ \text{ppm} \qquad (44)$$

The average exposure in the print shop:

$$C_2 = \frac{70 + 90 + 110 + 120}{4} = 98\ \text{ppm} \qquad (45)$$

Thus the TWA exposure for the 8-hour shift, excluding 60 minutes for lunch, is as follows:

$$\text{TWA} = \frac{(168\ \text{ppm})(3.5\ \text{hr}) + (98\ \text{ppm})(4.0\ \text{hr})}{8}$$
$$= 122.5\ \text{ppm} \qquad (46)$$

Example
As part of her job, a hospital central supply worker unloads sterilized materials from an ethylene oxide (EtO) sterilizer. She does this 4 times per eight-hour shift, it takes 15 minutes each time, and she has no other exposure to EtO during the shift. The eight-hour PEL for EtO is 1 ppm; the 15-minute excursion limit is 5 ppm. The following 15-minute sampling results were obtained: 4.8, 3.5, 4.9, and 3.4. None of the results exceeded the 5 ppm excursion limit. What is the 8-h PEL for this worker?

Solution

$$\frac{1}{480\ \text{min}}[(15\ \text{min})(4.8\ \text{min}) + (15)(3.5)$$
$$+ (15)(4.9) + (15)(3.4) + (420\ \text{min})(0\ \text{ppm})]$$
$$= 0.52\ \text{ppm} \qquad (47)$$

Excursions

TWA concentrations imply fluctuations in the level of airborne contaminant. Excursions above the TLV® are permissible if equivalent excursions below the TLV occur. The TLV booklet stipulates that short-term exposures may exceed three times the TLV for no more than a total of 30 minutes during the workday; under no circumstances should exposures exceed five times the TLV. This stipulation is valid if TLV–TWA is not exceeded. In some cases, a specific short-term exposure limit (STEL) has been established, for example, for formaldehyde and ethylene oxide.

INTERPRETATION OF RESULTS

Interpretation of the results obtained from sampling is the final step in evaluating the environment to which a worker is exposed. The chemicals monitored, the sites chosen for the sampling, and the timing of the monitoring all reflect the industrial hygienist's best judgment about which exposures might be significant. Potential sources of error and the limitations of the sampling and analytical methods have been taken into consideration. There are times when the interpretation of results is not a completely straightforward process and it is always important to keep in mind why the sampling was done. If it was done purely for compliance reasons, then OSHA standards are the absolute guide. If "good practices" are the ultimate goal, then ACGIH TLVs®, NIOSH RELs, or other recommended limits may be worth referencing. In either case, it is important to know whether the referenced standard is mandatory or recommended only, since the results may lie somewhere in between. Appropriate follow-up and expenditure of resources may depend on this.

As an example, a consultant Industrial Hygienist sampled for acetic acid during a weekly decontamination procedure in a Biotechnology firm's clean room, as a result of nuisance complaints from a non-laboratory neighbor. She looked to both OSHA and NIOSH for required or recommended occupational upper exposure limits. OSHA's PEL (eight-hour) is 10 ppm; NIOSH has a 15-minute, recommended Short Term Exposure Limit (STEL) of 15 ppm. Three 25-minute samples were taken during the procedure of interest; results were 11.7, 9.10, and 19.3 ppm.

If one were to do a PEL calculation, using the 19.3 ppm result and assuming no other exposure to acetic acid during the rest of the day, the result would be 4.82 ppm. This is clearly lower than the OSHA-regulated PEL and requires no further action. However, this same sample exceeds the 15-minute recommended NIOSH limit. While not required by law to reference limits other than OSHA's, most health professionals would probably cite the NIOSH limit as good practice and make changes in work practices or engineering controls to stay within the limits.

Comparison with Standards and Guidelines

The first step in evaluating sampling results is to compare them with the relevant standards and guidelines. The legally enforceable maximum allowed exposures in general industry are the OSHA permissible exposure limits, which have been determined for over 400 air contaminants and are listed in three tables in the *Code of Federal Regulations* (29 *CFR* 1910.1000). Additional comprehensive standards have been promulgated for other chemicals. Sampling results greater than the PEL and its lower confidence limit can result in citations and fines.

Because of the role of sampling results in legal proceedings, they must be analyzed in a cookbook fashion. For example, unless documentation exists that exposure levels are constant, any work time for which no sampling was conducted must be considered as unexposed time, and a zero is factored in any calculation of the time-weighted average. Consider, for example, the sampling results for chloroform presented in equation 39. The time-weighted average calculated for the six hours sampled was 57 ppm. The PEL for chloroform is 2 ppm. The ACGIH TLV®–TWA is 10 ppm. Clearly, the sampling results exceed both limits. NIOSH identifies chloroform as an occupational carcinogen, and therefore recommends that exposure be kept to the lowest feasible limit. NIOSH has not identified thresholds for carcinogens that will protect 100 percent of the population. A situation like the one in the example, that would result in such a high concentration of an occupational carcinogen, would require immediate action to prevent continued overexposure.

If the solvent measured had been methyl isobutyl ketone (hexone), which has a PEL of 50 ppm and a STEL of 75 ppm, and the six-hour TWA had also been 57 ppm, then the interpretation of the results would be different. At first, this might also appear to exceed the eight-hour PEL. However, there is an additional consideration in this case. Two hours of the employee's workday had not been sampled. If there is no documentation to prove that he was similarly exposed during the remaining time, a 0 ppm concentration could be factored into the eight-hour PEL calculation:

$$\frac{(57\ \text{ppm})(360\ \text{min}) + (0\ \text{ppm})(120\ \text{min})}{480\ \text{min}}$$

$$= 43\ \text{ppm} \qquad (48)$$

The sampling results remain the same, but the interpretation has changed. This result, 43 ppm, is in compliance with the PEL. Such a result would not lead to a citation for violation of 29 *CFR* 1910.1000, but it can be interpreted as a significantly high exposure to a volatile solvent, which should be controlled. Such an exposure has the potential to harm the respiratory system, eyes, skin, and central nervous system. If it is possible that the worker is exposed to methyl isobutyl ketone at some concentration during the time not sampled, it is possible that the sampling omission will allow workers to remain overexposed indefinitely.

The results calculated in the example described in equation 40 can be analyzed in a similar manner. The concentration of carbon monoxide (CO) is in compliance with the OSHA PEL and the NIOSH REL for an eight-hour TWA, despite the fact that during four hours of the day the worker is exposed to 50 ppm. The ACGIH TLV for CO is 25 ppm (this standard has been reduced over the years as the adverse effects of carbon monoxide exposure have been demonstrated at lower levels). At first glance, this result might be considered satisfactory because it does not exceed the OSHA PEL. However, because there is evidence that a lower level is recommended by the ACGIH, other questions might be triggered by these results: Are there excursions during the four hours over the STEL? Do results vary from day to day? Would the results be viewed as acceptable if the worker in this example were pregnant? Is it acceptable to leave the hazard in place and simply rotate different employees into the area, so that no single individual is overexposed, but all of them are exposed for part of the day? The best actions in response to these sampling data would be to identify the source of the CO for the four hours of exposure measured, to evaluate others who may be at risk of exposure, and to attempt to reduce exposure to the lowest feasible level.

Exposure limits can be compared to speed limits. Traveling one mile per hour less than the posted limit does not guarantee safety. In addition, chemical exposure has a cumulative effect if the time between exposures has not been sufficient to allow clearance of the chemical and its metabolites from the body and recovery from the adverse physiological effects.

Limitations of Standards

Any sampling result that is less than the PEL is considered to be in compliance with the law. This evaluation is often misinterpreted as meaning a clean bill of health. A review of OSHA's sampling results shows that 92 percent of them were in compliance (Senn, 1992), but OSHA estimates that hundreds of thousands of new cases of occupational illness occur annually. There have been many criticisms of the OSHA standards (Castleman & Ziem, 1988; Roach & Rappaport, 1990; Robinson et al, 1991; Tarlau, 1991), including the following:

➢ They evaluate only inhalation exposures.

- ➢ They are often out of date because updates take years and proceed very slowly; for example, by 1987, the ACGIH's TLV® list, which in 1968 formed the basis for OSHA's original PELs, contained 168 substances not regulated by OSHA, and had reduced guidelines for an additional 234 substances (Robinson et al, 1991).
- ➢ They have been based on inadequate research that fails to consider chronic toxicity data, including immune or endocrine system function, reproductive toxicity, and neurological changes.
- ➢ Standards are inadequate to protect employees who become sensitized to chemicals that may cause asthma, dermatitis, and other immunologically mediated effects.
- ➢ Standards were often adopted based on epidemiological data on workers who were mainly white and male, excluding analysis of nonwhite and female employees.
- ➢ They allow a level of risk not tolerated for general environmental exposure, such as a risk for cancer of one in a thousand compared to one in a million for environmental exposures.
- ➢ They fail to account for multiple exposures that are additive or synergistic.
- ➢ They offer limits for less than 10 percent of the chemicals in widespread commercial use.
- ➢ The sampling results reflect conditions on one day and may miss excursions that occur irregularly or peak exposures occurring only during maintenance, leaks, and emergencies.
- ➢ Rather than representing a more scientifically based guideline, at times they represent a political compromise between industry and labor regarding feasibility.

Industrial hygienists sometimes analyze sampling results and conclude that compliance with PELs is not sufficient to guarantee health in the workplace. Where NIOSH RELs and ACGIH TLVs® differ from PELs, these guidelines provide additional benchmarks that represent conclusions from research designed to further control exposures.

RELs exist for nearly 200 chemicals; NIOSH tends to propose more conservative exposure limits and has criticized several OSHA PELs as being insufficiently protective (Robinson et al, 1991). Most RELs were developed in the 1970s, and some have been outdated by more recent findings. NIOSH recommends, for example, that exposure to occupational carcinogens be reduced to "the lowest feasible limit," acknowledging the absence of thresholds that will protect 100 percent of the population.

Roach and Rappaport wrote an article in 1990, titled "But they are not thresholds: A critical analysis of the documentation of Threshold Limit Values," in which they analyzed 127 TLVs. They found that the literature cited in the TLV documentation showed that one in seven workers experienced adverse health effects when exposure was limited to concentrations below the TLVs. They observed that "factors other than health appeared to have influence in assignment of particular TLVs... the TLVs represent levels of exposure that were perceived by the committee to be realistic and attainable at the time." Other critics have charged that some TLVs were based on insufficient data on chronically exposed animals, or on analogy to similar chemicals rather than chemical-specific data.

Such deficiencies do not necessarily mean that all TLVs are wrong. Nor do they deny the contribution to worker health that resulted from the TLVs. They do, however, limit the conclusions that can be drawn when comparing air-sampling results with them.

Another concern regards the concept that ACGIH limits are not expected to protect "hypersusceptible" workers, a group described by Mastromatteo (1981), who was a member of the TLV committee for many years, as including those with genetic disorders, nutritional deficiencies, parasitic diseases, or preexisting diseases such as asthma or chronic bronchitis; those consuming alcohol or drugs; and cigarette smokers. Others have stated that large groups may be especially susceptible to hemolytic chemicals or pesticides, and that female workers may react to certain chemical exposures differently than males (Sentes, 1992).

The TLV process has been criticized as unduly influenced by corporations by Castleman and Ziem (1988). They wrote that unpublished corporate communications that were largely unavailable for independent scientific review were influential in developing TLVs for 104 substances. With unverifiable data, it could be argued that TLVs might inadequately protect workers. The Board of Directors of the ACGIH wrote in response (1990),

> *Many of the "personal communications" mentioned as a partial basis for some TLVs were from governmental health professionals and not corporations. Realizing the large gap in needed toxicity information for many substances, the ACGIH made a concerted effort through the Notice of Intended Changes process to obtain information* from all possible sources.

The ACGIH board also responded to the various criticisms with a defense of their process and intent. They reiterated "that TLVs® are developed as guidelines and not for use as legal standards." They noted important improvements that had been made in the TLV procedures, documentation, and research. Some of these included the following:

- ➢ Assigning of experienced occupational health professionals to staff the TLV effort
- ➢ Development and implementation of conflict of interest procedures
- ➢ Development of policies concerning TLV committee meetings with outside groups
- ➢ Printing of the last revision date of each TLV in the booklet
- ➢ Publication of a booklet listing a number of different recommended exposure guidelines, in addition to the TLVs, such as RELs, PELs, etc.
- ➢ Initiating the yearly publication of full text documentation for all intended changes for public comment

The task of providing guidance regarding risk in the absence of complete information often leads occupational health specialists to settle for existing data and guidelines without analyzing their adequacy. A minimum standard of care in many responsible industries is the maintenance of airborne chemical concentrations below all existing standards, guidelines, and internally generated standards. In addition, when employee health complaints persist when a standard is not exceeded, further investigation and action are often needed to ensure health. The Industrial Hygiene Code of Ethics (see Chapter 23) requires placing employee health first in all considerations.

Some have proposed reliance on the EPA's Integrated Risk Information System (IRIS) database for standard setting in the workplace. The IRIS database was developed by the EPA in the late 1980s to early 1990s to systematically review human and animal toxicological data on chemicals of environmental concern. This may be an additional resource in considering worker exposure guidelines that are more inclusive.

Comparison of Results with Other Data

Sampling may be conducted to investigate a problem or to measure the impact of changes in production processes or control measures. In these cases current sampling results can be compared to previous results to determine the effectiveness of the new or modified control measure in reducing airborne concentrations. In other cases, when the intent of the sampling is to evaluate the effectiveness of in-place monitors used for regular surveillance, the current data collected should also be compared to previous results.

It can also be helpful to review sampling data from various types of workplaces that are available from NIOSH *Health Hazard Evaluation* reports, in order to evaluate the effectiveness of the current sampling or the health and safety oversight at the worksite in question.

Industrial hygienists are sometimes asked to evaluate the significance of chemical-sampling results for which there are no published standards or guidelines. In these situations, the manufacturer may have developed internal standards for the chemical's use within the company. Lacking any other guidelines, a review of anecdotal reports in the literature, health surveys among those exposed on the job, or a careful consideration of animal toxicology data can be helpful. The LD_{50} (lethal dose for 50 percent of the exposed animal population in question during experiments) can be found in the Registry of Toxic Effects of Chemical Substances (RTECS) database from NIOSH. (See Appendix A, Additional Resources, for more information.) Animal research that establishes a "no-effect level" (NOEL) is especially useful.

While debate continues over the adequacy of standards and guidelines, industrial hygienists must still conduct air sampling and analyze results, attempting to make the best use of all that is available to them as evaluation tools, including their skills in measurement, observation, interviewing, and communication with employers and employees. In addition, they often consult with other professionals in the fields of occupational medicine, infection control, ventilation, architecture, engineering, health physics, and others to ensure a broad and in-depth analysis of an industrial hygiene problem. This networking with other professionals is invaluable in the evaluation process.

SUMMARY

There are many factors to consider in evaluating the workplace. Evaluation is a process that must incorporate new research, advances in production technology, a changing work force, and alterations in air-sampling methodology, with the most fundamental concern being the lives and health of workers. This is at the core of the code of ethics for industrial hygienists and forms the basis for all interactions with other health professionals in the practice of prevention of occupational illness and injury.

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Chapter 16

Air Sampling

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Industrial hygienists are responsible for the evaluation and control of employee exposure to occupational health hazards. For the evaluation and control of inhalation hazards, hygienists typically compare the measured concentration of an airborne chemical to a recognized exposure limit. Standardized methods for the collection of air samples have been developed to ensure that accurate and meaningful information is collected.

This chapter will review the different types of air sampling—personal versus area, grab versus integrated—and when each might be used; the components of a sampling train, including suction pumps and flow-rate meters; the collection devices and methods used to sample gases and vapors; the collection devices and methods used to sample particulates; how to select a sampling method; and how to calibrate sampling pumps.

TYPES OF AIR SAMPLING

Air sampling is used to evaluate employee exposure, assist in the design or evaluation of control measures, and document compliance with government regulations. These sampling objectives define the type of air sampling selected.

Personal Versus Area Sampling

Personal air sampling is the preferred method of evaluating worker exposure to airborne chemicals. The worker wears a sampling device that collects an air sample. The sampling device is placed as close as possible to the breathing zone of the worker (defined as a hemisphere in front of the shoulders with a radius of 6–9 in.) so the data collected closely approximate the concentration inhaled. (Concentration is equal to the mass of the contaminant collected divided by the volume of air passed through the collection device.)

Area air samples can be used to evaluate background concentrations, locate sources of exposure, or evaluate the effectiveness of control measures. The sampling device is

strategically placed in a fixed location in the area of interest. For example, if a leak is suspected in a process, several area samples taken at key locations could be used to pinpoint the source. In general, this type of sampling is not used to provide an estimate of worker exposure because conditions at the fixed location may not be the same as those experienced by the worker.

Grab Versus Integrated Sampling

Grab samples are taken to measure the airborne concentration of a substance over a short time period (usually less than 5 min). Personal or area grab samples are used to identify peak or ceiling concentrations.

Grab samples alone are rarely used to estimate an employee's eight-hour time-weighted average exposure. This is because they do not account for the time between samples. However, they can be used as a screening method to determine whether more extensive sampling is needed. For example, if grab samples and observations indicate that the concentration of a chemical is well below the eight-hour time-weighted average exposure limit, then sampling for the full shift *may* not be necessary.

Integrated air sampling is used to estimate a worker's 8-h or 15-min exposure to a particular substance by collecting one or more personal air samples for the duration of a particular task or workshift. It is called integrated sampling because the result integrates all of the various concentrations to which the worker has been exposed during the sampling period. The resulting concentration represents an average exposure over the sampling period, also known as a *time-weighted average (TWA).*

AIR-SAMPLING INSTRUMENTS

There are two categories of air-sampling equipment: direct-reading instruments and sample collection devices. Direct-reading instruments provide an immediate measurement of concentration. These devices are covered in Chapter 17, Direct-Reading Instruments for Gases, Vapors, and Particulates. Sample collection devices collect a sample of air that is subsequently analyzed or weighed at a laboratory. These devices are the focus of this chapter.

Sampling Train

Air-sample collection devices are made of five basic components: an air inlet orifice, a collection device, an airflow meter, a flow-rate control valve, and a suction pump (see Figure 16–1).

Air enters the sampling train through the orifice and the chemical is collected on a collection medium such as a filter. The airflow rate is set using the rate control valve. Airflows are usually in liters or cubic centimeters of air per minute. Many air-sampling pumps have built-in flow-rate meters to visually gauge the flow rate. The suction pump moves air through all of the components of the sampling train.

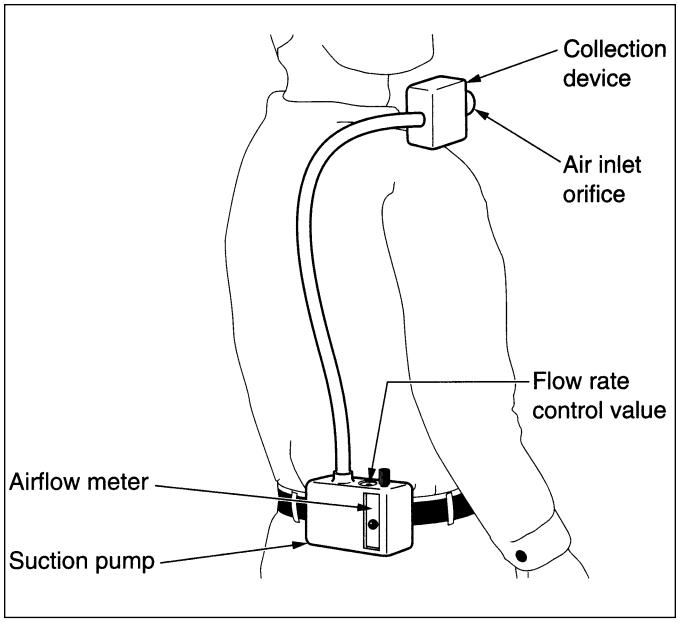

Figure 16–1. Components of a typical air-sampling train used to collect airborne particulates.

COLLECTION DEVICES FOR GASES AND VAPORS

Gases and vapors are formless fluids that completely occupy a space or enclosure. A substance is considered a gas if this is its normal physical state under standard temperature and barometric pressure conditions (70 F and 760 mmHg). A vapor is the gaseous phase of a substance that under standard conditions exists as a liquid or a solid in equilibrium with its vapor.

In some cases, a chemical may exist as both a gas or vapor and a solid particle at the same time. Polyaromatic hydrocarbons are an example. For such chemicals, collection devices for both the gaseous and solid phases must be used.

Gases and vapors behave similarly. They follow the ideal gas laws in that their volume is affected by changes in temperature and pressure. They mix freely with the general atmosphere and quickly form homogeneous mixtures with other gases.

Grab Sampling

Although direct-reading devices are usually used for grab sampling, the collection of a known volume of air for subsequent laboratory analysis is also used. Figures 16–2 and 16–3 are examples of the most commonly used collection devices, the evacuated container and the gas-sampling bag.

The advantages of grab sampling are that it is inexpensive, it is simple to use, and it normally collects 100 percent of the chemical. The disadvantage is that usually it cannot be used to sample reactive gases such as hydrogen sulfide, nitrogen dioxide, and sulfur dioxide unless the samples are analyzed immediately. Reactive gases can react with atmospheric dust particles, other gases, moisture, container sealant compounds, or the container itself, producing erroneous results.

Integrated Air Sampling

Integrated air sampling involves the extraction of a gas or vapor from a sample airstream followed by laboratory analysis. Two extraction techniques are normally used: absorption and adsorption.

ABSORPTION

In the absorption technique, a gas or vapor is removed from the airstream as it passes through an absorption liquid. The liquid can be highly soluble and nonreactive with the gas or vapor or it can contain a reactive reagent. Deionized water, for example, is a commonly used absorbing solution for acids because acids are highly soluble in water. A reactive absorbing reagent captures a gas or vapor by quickly reacting with it and creating a more stable compound, which can be analyzed by a laboratory. An example of these is Girard T reagent, which is used to sample for acetaldehyde.

Absorption devices include gas wash bottles, spiral absorbers, and fritted bubblers (Figure 16–4). The simplest is the gas wash bottle, which forces air through a nozzle into the absorbing solution. Because absorbing solutions do not collect 100 percent of the gas or vapor passing through, sometimes two impingers are used in series. This increases the total amount of vapor or gas collected. The spiral absorber forces the air to follow a spiral path through the liquid, which increases the amount of time the air and liquid are in contact with each other. The increased contact time increases the amount of material absorbed. The same concept is used in the fritted bubbler, where many tiny bubbles are formed as air is forced through the fritted surface. This increases the surface area of air in contact with the absorbing liquid. The spiral absorber and the fritted bubbler are used for gaseous substances that are only moderately soluble or that react slowly with the absorbing liquid.

Figure 16–2. An evacuated container is used to collect air for analysis. (Courtesy MDA Scientific.)

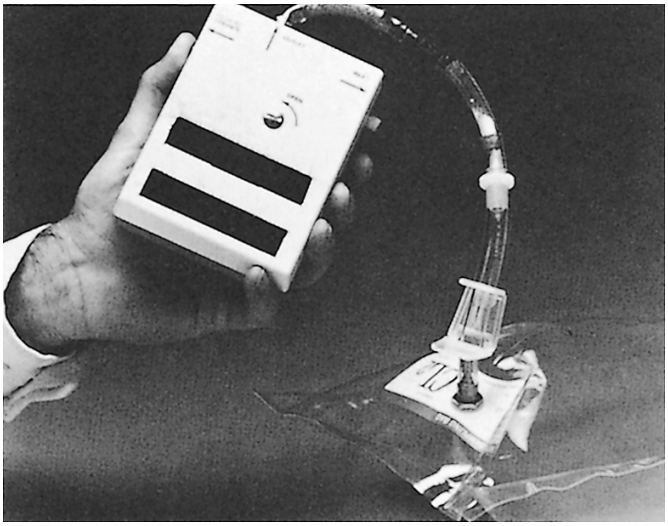

Figure 16–3. Portable, battery-operated pumps used to fill flexible plastic gas-sampling bags with air for analysis. (Courtesy MSA.)

The most commonly used gas wash bottle is the midget impinger. The impinger is placed inside a holster (Figure 16-5) and attached to the worker's shirt collar. During the course of work, the worker may accidentally invert the impinger, causing the absorbing liquid to be drawn into the sampling pump. To avoid this, an empty bottle or impinger is connected to the sampling train to collect spilled liquid. Although this precaution prevents damage to the pump, the recovered liquid is contaminated and cannot be used for an analysis. The use of spillproof midget impingers has minimized this problem. Table 16–A lists selected National Institute for Occupational Safety and Health (NIOSH) impinger sampling methods.

ADSORPTION

Air sampling for insoluble or nonreactive gaseous substances is commonly conducted using tubes filled with a granular sorbent such as activated charcoal or silica gel. The gas or vapor is retained or adsorbed, physically and chemically unchanged, onto the surface of the sorbent for subsequent laboratory extraction and analysis.

Activated charcoal is the most widely used solid sorbent for adsorbing organic vapors. The charcoal most commonly used is from coconut shells. Coconut shell charcoal provides a large adsorptive surface area and is electrically nonpolar, meaning it preferentially adsorbs organic vapors rather than polar molecules such as water vapor. A standard charcoal tube is 7 cm long and 4 mm wide, and is divided into two sections. The first section contains 100 mg of charcoal and a fiberglass, glass

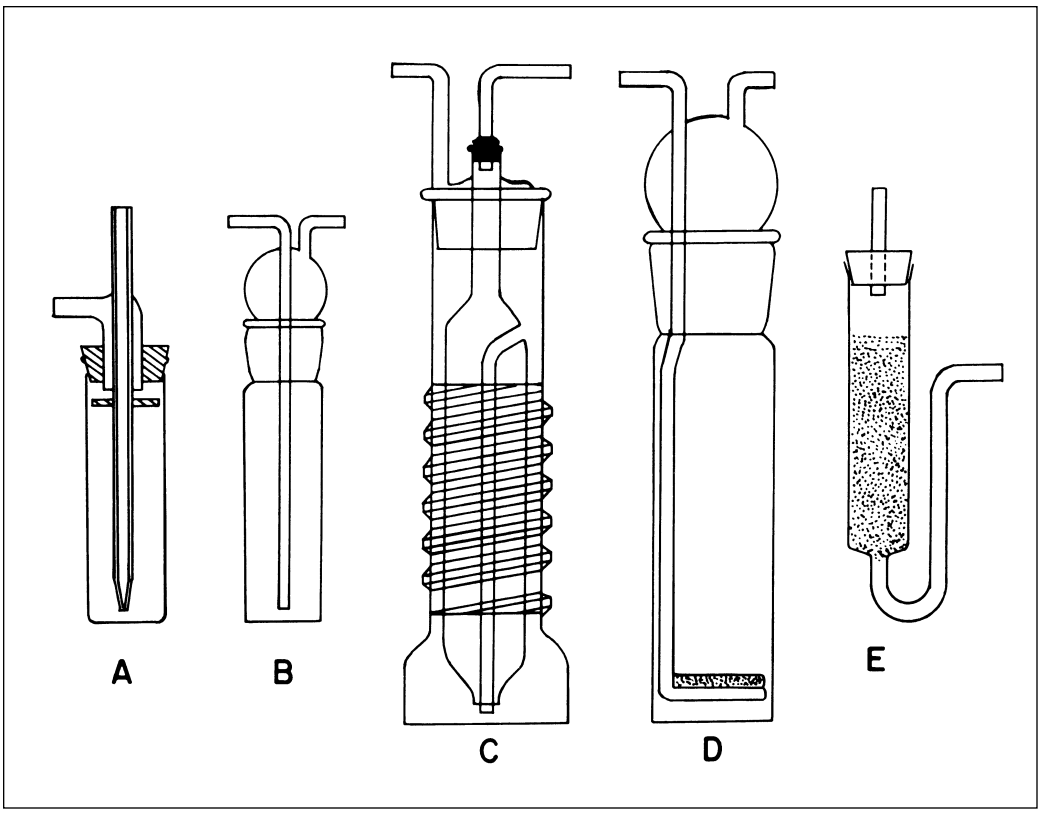

Figure 16–4. Basic absorbers are shown: gas washing (A and B), helical (C), fritted bubbler (D), and glass-bead column (E). They provide contact between sampled air and liquid surface for absorption of gaseous contaminants. (Reprinted from Powell CH, Hosey AD (eds.). *The Industrial Environment—Its Evaluation and Control,* PHS Publication No. 614-1965.)

wool, or urethane foam plug; the backup section contains 50 mg of charcoal (Figure 16–6). Other sizes are also available.

Although activated charcoal has a large adsorptive capacity, some contaminants invariably pass through the first section. The backup section increases collection efficiency by adsorbing some of the material that was initially missed.

Breakthrough describes a condition in which the mass of a collected gas or vapor in the backup section is greater than 10 percent of the mass in the front section. This means that a significant quantity of the contaminant may not have been collected. The calculated concentration, therefore, is of questionable validity. Sampling methods that specify the

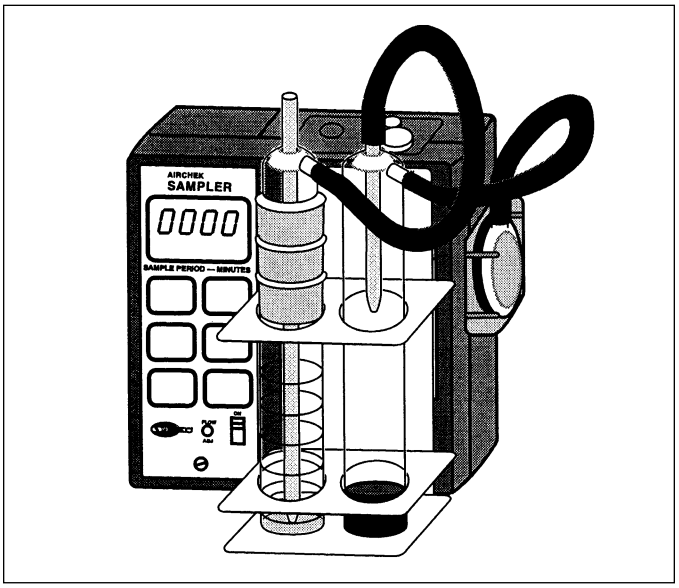

Figure 16–5. Midget impingers are sometimes used to collect personal air samples. They are placed in holsters so they can be worn in the worker's breathing zone. (Courtesy SKC, Inc.)

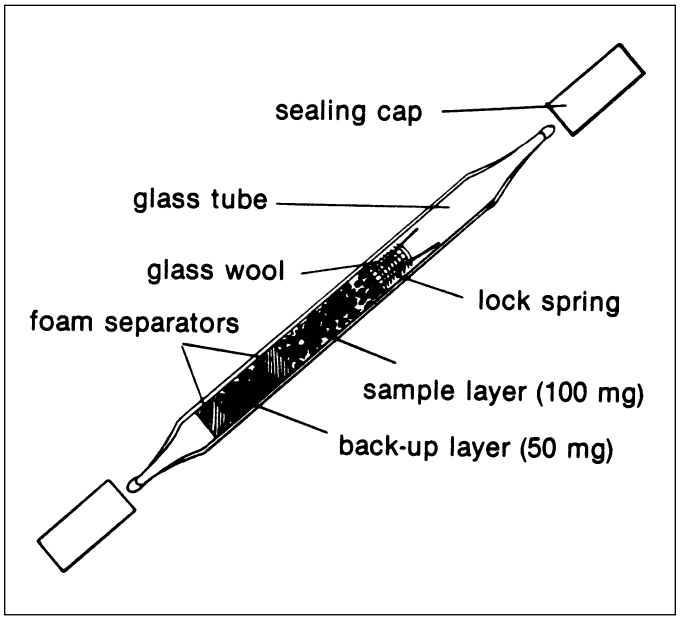

Figure 16–6. Standard activated charcoal tube used in organic vapor sampling. (Courtesy SKC, Inc.)

Table 16–A. *Selected NIOSH Impinger Sampling Methods*

Chemical	*NIOSH Sampling Method No.*	*Impinging Solution*	*Analytical Method*
Aminoethanol compounds II	3509	15 mL of 2 mM hexanesulfonic acid	Ion chromatography
Monomethylaniline	3511	10 mL of 0.05 M sulfuric acid	Gas chromatography
Acetaldehyde	3507	15 mL of Girard T reagent	High-pressure liquid chromatography
Isocyanates	5521	Solution of 1-(2-methoxyphenyl)-piperazine in toluene	High-pressure liquid chromatography

maximum sample volumes and recommended flow rates are designed to prevent breakthrough.

Charcoal tubes have a high adsorptive capacity for a large range of organic vapors. They can be used to sample several kinds of vapors at once. However, the analyzing laboratory should be consulted to determine whether there is a limit to the number of organic vapors that can be extracted or whether any of the sampled organic vapors must be collected separately.

Silica gel tubes are used to sample for gases and vapors that cannot be efficiently collected or extracted from activated charcoal. They are constructed in the same manner as charcoal tubes except that an amorphous form of silica is used as the adsorbent material. Silica gel is not as commonly used as activated charcoal because it is electrically polar and tends to attract interfering polar molecules such as water vapor.

Many solid sorbent materials with chemical coatings have been developed to sample for reactive gases and vapors that are not efficiently collected by charcoal or silica gel. These include XAD-2, Tenax-GC, Ambersorb, and Chromosorb tubes (see Table 16–B).

Passive Monitors

Passive monitors allow personal sampling without the use of sampling pumps. Whereas solid sorbent tubes rely on a sampling pump to draw air through the adsorbing material, passive monitors (Figure 16–7) rely on passive diffusion. Diffusion is the passage of molecules through a semipermeable barrier. It occurs because molecules tend to move from an area of high concentration to an area of low concentration. If the ambient concentration of a particular gas or vapor is greater than the concentration inside the monitor, then the gas or vapor molecules will diffuse across a barrier into the monitor and be collected by a sorbent material (Figure 16–8). As the sorbent adsorbs the gas or vapor, the concentration inside the monitor becomes less than the concentration outside. The rate of diffusion is determined by the manufacturer of the device.

Monitoring begins when the device's cover is removed; the time is recorded. The worker wears the monitor in his or her breathing zone. When sampling is complete, the monitor is removed and resealed and the time is recorded. The badge is then sent to the laboratory for analysis.

Passive monitors are used because they are inexpensive and easy to use. Their accuracy has been studied extensively. Most commercially available monitors meet or exceed NIOSH accuracy requirements (±25 percent for 95 percent of samples tested between 0.5 and 2.0 times the exposure limit).

COLLECTION DEVICES FOR PARTICULATES

Airborne particulates can be either solid or liquid. Dusts, fumes, smoke, and fibers are dispersed solids; mists and fogs are dispersed liquids. They range in size from visible to microscopic. A number of devices can be used to collect particulates, each using different mechanisms for particle capture (see Table 16–C).

Filters

The filter is the most common collection device for particulates. There are several types, including glass fiber (GF), mixed cellulose ester fiber (MCE), and polyvinyl chloride

Table 16–B. *NIOSH-Recommended Sorbent Tubes*

Chemical	*NIOSH Method No.*	*Tube*	*Analytical Method*
Methanol	2000	Silica gel	Gas chromatograph
Aromatic amines	2002	Silica gel	Gas chromatograph
Halogenated hydrocarbons	1003	Charcoal	Gas chromatograph
Naphthas	1550	Charcoal	Gas chromatograph
Phosphorus	7905	Tenax GC	Gas chromatograph
Nitroethane	2526	XAD-2	Gas chromatograph
Methyl ethyl ketone	2500	Carbon molecular sieve	Gas chromatograph
n-Butyl mercaptan	2525	Chromosorb 104	Gas chromatograph

Figure 16–7. Passive diffusion monitors are an inexpensive and easy-to-use alternative to solid sorbent tubes. (Courtesy 3M.)

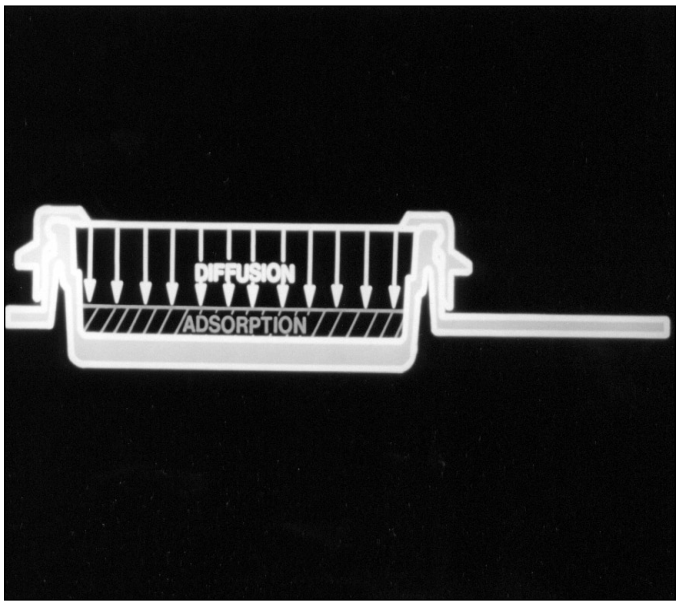

Figure 16–8. Gas or vapor molecules diffuse into a passive diffusion monitor across a permeable barrier and are collected by a sorbent material. (Courtesy 3M.)

(PVC) filters. They are selected based on their ability to collect material and their suitability for laboratory analysis. For mineral and nuisance dusts, for example, the total weight of the collected particulate is of concern. In this case, PVC filters are used because they can be easily weighed. For metal dusts, the amount of a particular metal in the sample is of concern, so a chemical analysis must be done. MCE filters are generally used in this case. See Table 16–D for a list of NIOSH-recommended filters.

A typical collection device used for particulate sampling is a closed-face filter cassette, 37 mm in diameter, containing a filter supported with a cellulose backup pad (Figure 16–9). *Closed-face* means that the top of the cassette is not removed during the sampling; only the top and bottom caps are removed. The air inlet side of the cassette, opposite the filter, is usually marked so that the filter is not attached backwards.

There are some exceptions to the standard filter setup. Asbestos, for example, is collected using a 25-mm filter and cassette with an *open-face* 50-mm conductive extension cowl (Figure 16–10). The cassette is used open-faced because an even distribution of fibers on the filter is needed for microscopic analysis. The 25-mm filter improves the sensitivity of the test. The electrically conductive extension cowl reduces the number of asbestos fibers attracted to the sides of the cassette by static electricity.

Table 16–C. ***Sampling Techniques for Collection of Airborne Particulates***

Sampling Technique	*Force or Mechanism*	*Examples*
Filters	Combination of inertial impaction, interception, diffusion, electrostatic attraction, and gravitational forces	Various types and sizes of fibrous, membrane, and nucleopore filters with holders
Impactors	Inertial–Impaction on a solid surface	Single- and multijet cascade impactors and single-stage impactors
Impingers	Inertial–Impingement and capture in liquid media	Greenburg-Smith and midget impingers
Elutriators	Gravitational separation	Horizontal and vertical elutriators
Electrostatic precipitation	Electrical charging with collection on an electrode of opposite polarity	Tube type, point-to-plane, and plate precipitators
Thermal precipitation	Thermophoresis–Particle movement under the influence of a temperature gradient in the direction of decreasing temperature	Various devices for particulate collection for microscopy analysis
Cyclones	Inertial–Centrifugal separation with collection on a secondary stage	Tangential and axial inlet cyclones in varying sizes

(Reprinted from *Occupational Respiratory Diseases*, Pub. no. DHHS (NIOSH) 86-102, 1986.)

Table 16–D. *Selected NIOSH-Recommended Filters*

Chemical	*NIOSH Sampling Method No.*	*Filter*	*Analytical Method*
Copper	7300	MCE	Atomic emission spectroscopy
Carbon black	5000	PVC	Gravimetric
Mineral oil mist	5026	PVC or MCE	Infrared spectrophotometry
Asbestos	7400	25-mm MCE	Phase contract microscopy
Arsenic trioxide as As	7901	Na_2Co_3-impregnated MCE	Atomic absorption, graphite furnace
(2,4-Dichlorophenoxy) acetic acid	5001	GF	High-pressure liquid chromatography

Cyclones

A cyclone is used to collect particles of respirable size. Respirable particles are those that are retained in the lung and are generally considered to be of an aerodynamic size below 10 µm. Cyclones have traditionally been used to sample for mineral dusts containing crystalline silica because of the strong association between the respirable dust fraction and lung disease silicosis.

Air is drawn into a cyclone tangentially through a small orifice. It is important that the cyclone is operated at the airflow rate for which it was designed. The centrifugal motion of the air inside the cyclone forces the larger particles to the periphery of the airstream, where they fall to the bottom of the cyclone. The respirable particles, in the center airstream, are drawn upward onto a preweighed filter. After sampling is completed, the filter is analyzed or weighed to determine how much material has been collected.

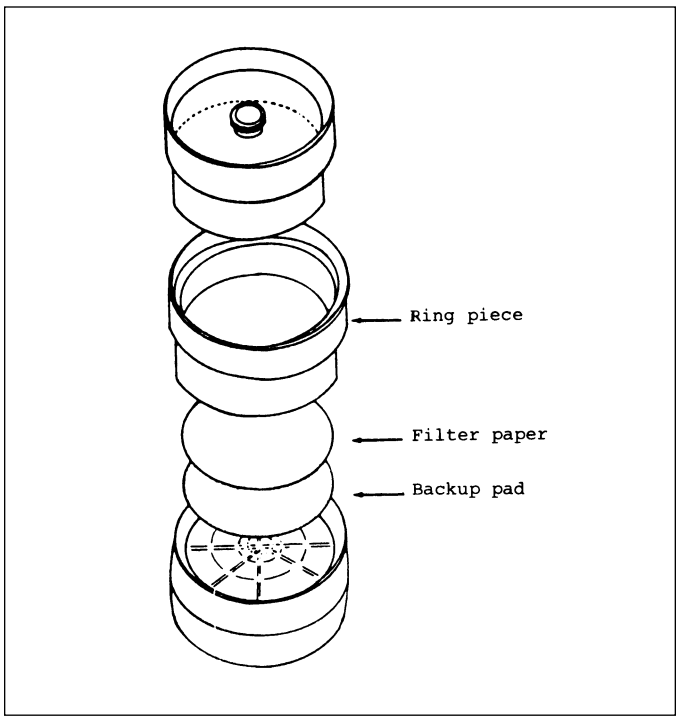

Figure 16–9. Standard filters are 37 mm in diameter and are placed in closed-face cassettes with a backup pad, which prevents contamination. (Reprinted from OSHA Technical Manual.)

Use of a 10-mm nylon or aluminum cyclone (Figure 16–11) is currently the most common method of collecting respirable dust samples in the United States. It meets the particle size selection efficiency guidelines (Table 16–E) of the American Conference of Governmental Industrial Hygienists (ACGIH) for respirable particulates.

These guidelines specify how much of each particle size range the cyclone must collect. These values were selected because they approximate the percentages of inhaled particles that are retained in the gas-exchange (alveolar) region of the lung.

Electrostatic Precipitators

Electrostatic precipitators use an electric charge to remove particles from the sampled air. As the particles pass through a high-voltage electric field, they acquire a charge and are attracted to an oppositely charged electrode. Collection efficiency increases with the length of passage through the collector, so precipitators are often used in series. Electrostatic precipitators are used when the required sample air volume is large, high-collection efficiency is required for very small

Figure 16–10. Air sampling for asbestos is conducted using a three-piece cassette, a 50-mm black conductive cowl, and a 25-mm filter. (Courtesy MSA.)

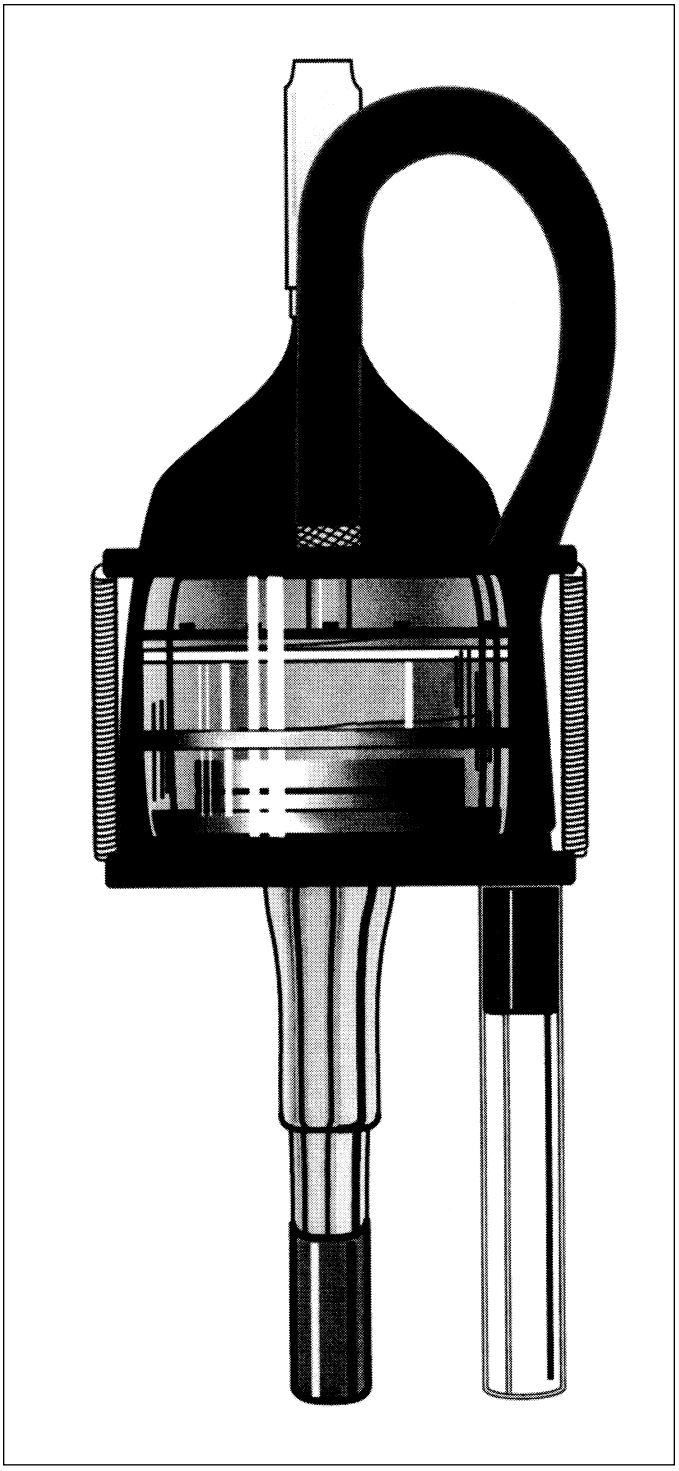

Figure 16–11. A cyclone attached to a filter cassette is used to sample for respirable dust. The filter cassette holder can be placed in the worker's breathing zone. (Courtesy SKC, Inc.)

particles (such as fumes), there is a possibility of filter clogging, or high-temperature airstreams must be sampled.

Inertial Impactors

Inertial impactors collect particles by impacting them onto a surface. If an obstacle causes a moving airstream to deviate from a straight course, the particles in the airstream tend to leave the airstream and impact on the obstacle. Obstacles include filter paper, glass, stainless steel, and in the case of bioaerosol sampling, nutrient agar. The collection efficiency of this method is affected by the mass of the particles, the size and shape of the obstacle, and the velocity of the air.

Inertial impactors can be used to determine particle size distribution. The mini-cascade impactor (Figure 16–12) is constructed with a series of stages, each of which is calibrated to collect particles of a certain aerodynamic size range.

Table 16–E. *ACGIH Guidelines for Particle Size Collection*

Particle Aerodynamic Diameter (μm)	*Respirable Particulate Mass (%)*
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

Impingers

The impinger is one of the oldest methods of particulate sampling, but it is little used today. It is used in situations where the number of particles must be expressed in millions of particles per cubic foot of air (mppcf).

Impingers use the same particle collection method as the inertial impactor, except that the particles are collected in a liquid (usually water). Air is drawn at high velocity into a liquid-filled flask through a glass nozzle or jet. The particles impinge on a flat plate or the bottom of the flask, lose their velocity, and are trapped in the liquid. A small sample of the liquid is collected and then placed in a special cell that allows the particles to be counted and sized as they are viewed under a light microscope.

Impingers do not collect very small particles (less than 0.7 μm) well. For maximum collection efficiency, the air must be drawn at such a high velocity that larger particles are often shattered, thus producing erroneous results.

Elutriators

Elutriators are used in front of a sampling train to remove coarse particles. The coarse particles are removed by gravity; the smaller particles remain suspended and are collected for subsequent analysis.

There are two types of elutriators: horizontal and vertical. The vertical elutriator is commonly used for cotton dust sampling. It consists of a large vertical tube through which the direction of airflow is opposite to the direction of gravity. Due

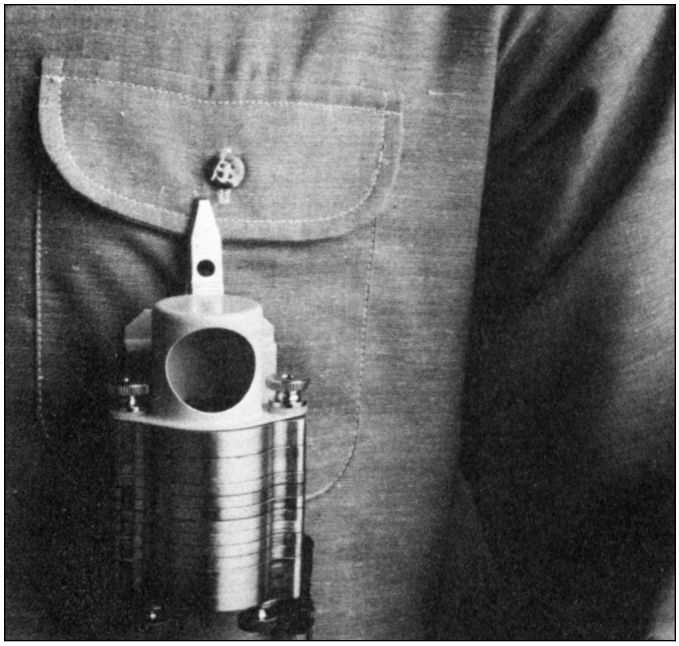

Figure 16–12. Cascade impactor. (Courtesy Anderson Sampler, Inc.)

to the airflow requirements and elutriator size, it must be operated in a stationary position. The flow rate is very important because if it is too high, the larger particles will not settle out but will be collected on the filter. If the flow rate is too low, some of the smaller particles may settle out and not be collected.

SUCTION PUMPS

Suction pumps are responsible for the movement of air through the sampling train. To select the type of pump that meets the needs of a particular sampling procedure, one must consider the airflow rate required, the pump's ease of use, and the pump's suitability for use in a potentially hazardous or flammable environment.

Most personal sampling pumps (Figure 16–13) are lightweight and quiet, use nickel/cadmium rechargeable batteries, and can be easily attached to the worker's belt. Each has a flow rate control valve and some are programmable. They must approved by the Mine Safety Administration, Underwriters Laboratory, or Factory Mutual Engineering Corp. for use in flammable or explosive atmospheres if they are to be used in such atmospheres.

Air-sampling pumps are generally available in the following airflow rate ranges: low-flow (0.5–500 mL/min), high-flow (0.5–5 L/min), and dual range (high- and low-flow).

Low-flow pumps are used for solid sorbent tube sampling. High-flow pumps are used for filter, cyclone, and impinger sampling.

However, there are situations where higher airflow rates are needed. The EPA, for example, requires a minimum air volume of 1,200 L for clearance area monitoring after an asbestos abatement project. Using a high-flow air-sampling pump with a flow rate of 5 L/min to sample 1,200 L of air would be very time-consuming. In this case, pumps that provide a flow rate of up to 10 L/min are used.

The low-power circuitry and sensors, amplifiers and microprocessors, and light plastic cases of the newer pumps have increased their susceptibility to radiofrequency (RF) interference. RF can be generated from facility or communications equipment and may alter the airflow rate or cause the pump to stop. Many manufacturers are now providing RF shielding.

FLOW-RATE METERS

Maintaining a constant flow rate during sampling is critical. Devices that help maintain a constant flow rate are pressure-compensating devices and critical-flow orifices.

Pressure-Compensating Devices

Pressure-compensating devices are designed to overcome the flow-rate variations inherent in many sampling situations. A sampling pump will slow down if the filter becomes loaded with dust or the hose is crimped. Pumps with pressure-compensating devices have sensors with feedback mechanisms that detect pressure changes and maintain the preset flow rate.

Critical-Flow Orifice

Some pumps use critical or limiting orifices to regulate the airflow rate. A critical orifice is a precisely drilled hole in a metal plate through which the airstream being sampled is directed. When certain parameters are met, the flow rate through the orifice remains constant despite conditions at the inlet (such as a clogged filter). A critical orifice attached to a sampling pump causes the pump to draw air at the desired flow rate.

The principle of the method is to draw air through the orifice under critical-flow conditions and constant upstream

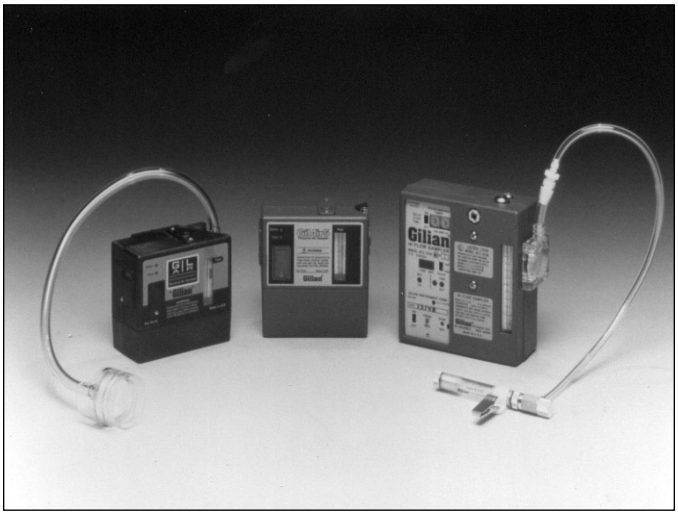

Figure 16–13. Personal sampling pumps must be lightweight and easy to use. (Courtesy Gillian Instrument Corp.)

pressure. The volume flow rate of a gas through an orifice will increase with a decrease in the ratio of downstream pressure (p_2) to upstream absolute pressure (p_1) until the velocity through the opening reaches sonic velocity. The ratio, p_2/p_1, at which acoustic velocity is attained is called the critical pressure ratio. The velocity through the orifice will remain constant even if a much lower downstream pressure exists. Therefore, when the pressure ratio is less than critical, the rate of flow through the orifice is dependent only on upstream pressure.

Orifices are calibrated under certain temperature and air pressure conditions. If the air sampling is conducted at a significantly different temperature and pressure, then a correction factor must be used to determine the actual airflow rate. (See the formula under Calibration Procedures later in this chapter.)

Some sampling pumps do not have a mechanism to maintain a constant airflow rate. In these cases, a calibration device such as a precision rotameter can be used to check the airflow rate during the sampling period. (Precision rotameters are discussed later in this chapter.) If the rate changes, it is manually adjusted to the desired rate using the flow-rate control valve.

SAMPLING METHODS

The selection of a sampling method depends on a number of factors:

- ➢ The sampling objective (documenting exposures, determining compliance, pinpointing sources of exposure)
- ➢ The physical and chemical characteristics of the chemical
- ➢ The presence of other chemicals that may interfere with the collection or analysis of the chemical
- ➢ The required accuracy and precision
- ➢ Regulatory requirements
- ➢ Portability and ease of operation
- ➢ Cost
- ➢ Reliability
- ➢ Type of sampling needed (area, personal, grab, integrated)
- ➢ Duration of sampling

Standardized sampling methods provide all the information needed to sample the air for a particular chemical. Analytical procedures are found in the NIOSH *Manual of Analytical Methods* and the OSHA *Chemical Sampling Information CD-ROM*. OSHA regulations do not specify a particular sampling method, but they do require that the method used have a specified and proven degree of accuracy. Some analytical laboratories have developed their own procedures that meet or exceed the OSHA criteria.

The sampling method used depends on the recommendations of the laboratory selected to analyze the samples. The laboratory must be experienced in industrial hygiene sampling methods and should be accredited by AIHA and involved in the NIOSH Proficiency Analytical Testing Program. These organizations monitor laboratory performance to ensure that the information and analytical results are accurate.

An example of a NIOSH sampling procedure is given in Figure 16–14.

This sampling method for acetic acid provides information for both the industrial hygienist and the laboratory. The method requires a coconut shell charcoal tube (100 mg of charcoal with a 50-mg backup section), an airflow rate between 0.01 to 1.0 L/min and an air sample volume between 20 and 300 L. Precautions include analyzing the samples within seven days and ensuring that the atmosphere being tested does not contain formic acid, which interferes with the analysis.

The recommended air sample volumes are important guidelines to follow. The minimum air sample volume is the minimum amount of air needed to ensure analytical accuracy. It also allows the laboratory to analyze the sample to a concentration well below the exposure limit for that chemical. This is called the sampling method's lower limit of detection and is the smallest amount of the chemical that the laboratory can detect.

Minimum sample volumes can be calculated if the lower limit of detection (LOD) of the analytical method is known. This can be useful if there is no listed minimum air sample volume or if the listed volume is quite large. Published values must assume worst-case conditions are present and have built-in safety factors to ensure that an adequate volume is collected. If the concentration of the contaminant can be estimated, then the following formula can be used:

$$SV = \frac{LOD}{EL \times F} \quad (1)$$

where SV = Minimum sample volume (L)
LOD = Lower limit of detection (μg)
EL = Exposure limit (mg/m^3)
F = Anticipated fraction of threshold limit value (TLV®) in atmosphere (decimal)

The LOD for acetic acid is 0.01 mg (10 μg). If the anticipated concentration is 25 percent of the TLV®, then the minimum sample volume is calculated as follows:

$$SV = \frac{10\ \mu g}{25\ mg/m^3 \times 0.25} = 1.6\ L \quad (2)$$

Establishing a maximum air sample volume is necessary to prevent breakthrough when sampling for gases and vapors or overloading the filter when sampling for particles. Breakthrough occurs when a significant quantity of a gas or vapor passes uncollected through a collection device. It happens when the device is saturated with the chemical or interfering chemicals or the airflow rate is too fast. In particulate sampling, if the filter is overloaded it may cause the suction pump to slow down or quit, cause the loss of some of the sample as the filter is being handled in the laboratory, or

ACETIC ACID

CH_3COOH MW: 60.05 CAS: 64-19-7 RTECS: AF1225000

METHOD: 1603, Issue 2 **EVALUATION: FULL** **Issue 1: 15 May 1989**
Issue 2: 15 August 1994

OSHA : 10 ppm
NIOSH: 10 ppm; STEL 15 ppm
ACGIH: 10 ppm; STEL 15 ppm
(1 ppm = 2.46 mg/m^3 @ NTP)

PROPERTIES: liquid; d 1.049 g/mL @ 25 °C;
BP 118 °C; MP 17 °C;
VP 1.5 kPa (11.4 mm Hg) @ 20 °C;
explosive range 5.4 to 16% v/v in air

SYNONYMS: glacial acetic acid; methane carboxylic acid; ethanoic acid

SAMPLING

SAMPLER: SOLID SORBENT TUBE (coconut shell charcoal, 100 mg/50 mg)

FLOW RATE: 0.01 to 1.0 L/min

VOL-MIN: 20 L @ 10 ppm
-MAX: 300 L

SHIPMENT: routine

SAMPLE STABILITY: at least 7 days @ 25 °C

BLANKS: 2 to 10 field blanks per set

ACCURACY

RANGE STUDIED: 12.5 to 50 mg/m^3 [1] (173-L samples)

BIAS: 5.4%

OVERALL PRECISION ($\hat{S}_{rT}$): 0.058 [1]

ACCURACY: ± 15.5%

MEASUREMENT

TECHNIQUE: GAS CHROMATOGRAPHY, FID

ANALYTE: acetic acid

DESORPTION: 1 mL formic acid; stand 60 min

INJECTION VOLUME: 5 µL

TEMPERATURE-INJECTION: 230 °C
-DETECTOR: 230 °C
-COLUMN: 130 to 180 °C, 10°/min or 100 °C isothermal

CARRIER GASES: N_2 or He, 60 mL/min

COLUMN: 1 m x 4-mm ID glass; Carbopack B 60/80 mesh/3% Carbowax 20M/0.5% H_3PO_4

CALIBRATION: standard solutions of acetic acid in 88 to 95% formic acid

RANGE: 0.5 to 10 mg per sample

ESTIMATED LOD: 0.01 mg per sample [2]

PRECISION ($\hat{S}_r$): 0.007 @ 0.3 to 5 mg per sample [1,3]

APPLICABILITY: The working range is 2 to 40 ppm (5 to 100 mg/m^3) for a 100-L air sample. High (90% RH) humidity during sampling did not cause breakthrough at 39 mg/m^3 for 4.6 hrs [1].

INTERFERENCES: Formic acid contains a small amount of acetic acid which gives a significant blank value. High-purity formic acid must be used to achieve an acceptable detection limit. Alternate columns are 3-m glass, 2-mm ID, 0.3% SP-1000 + 0.3 % H_3PO_4 on Carbopack A and 2.4-m x 2-mm ID glass, 0.3% Carbowax 20M/0.1% H_3PO_4 on Carbopack C.

OTHER METHODS: This revises Method S169 [3].

Figure 16–14. NIOSH Sampling Method 1603 provides guidelines for acetic acid sampling. (Reprinted from NIOSH *Manual of Analytical Methods,* 1994.) *(Continues)*

REAGENTS:

1. Formic acid, aqueous 88% to 95%, high-purity (<0.02% acetic acid).*
   NOTE: The acetic acid content varies from lot to lot of formic acid. Test each lot before use.
2. Glacial acetic acid, reagent grade.*
3. Propionic acid, reagent grade.
4. Eluent: Formic acid, 88% to 95%, with 0.1% v/v propionic acid or other suitable internal standard.
5. Nitrogen, purified.
6. Hydrogen, prepurified.
7. Air, filtered.

EQUIPMENT:

1. Sampler: glass tube with plastic caps, 7 cm long, 6-mm OD, 4-mm ID, flame-sealed ends, containing two sections of activated (600 °C) coconut shell charcoal (front = 100 mg; back = 50 mg) separated by a 2-mm urethane foam plug. A silylated glass wool plug precedes the front section and a 3-mm urethane foam plug follows the back section. Pressure drop across the tube at 1 L/min airflow must be less than 3.4 kPa. Tubes are commercially available.
2. Personal sampling pump, 0.01 to 1 L/min, with flexible connecting tubing.
3. Gas chromatograph, flame ionization detector, integrator and column (see page 1603-1).
4. Vials, 2-mL, PTFE-lined caps.
5. Syringes, 10-µL and other convenient sizes for preparing standards, readable to 0.1 µL.
6. Volumetric flasks, 10-mL.

* See Special Precautions

SPECIAL PRECAUTIONS: Care should be taken to avoid skin contact with formic acid and/or acetic acid. These reagents may cause severe burns.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Break the ends of the sampler immediately before sampling. Attach sampler to personal sampling pump with flexible tubing.
3. Sample at an accurately known flow rate between 0.01 and 1 L/min for a total sample size of 20 to 300 L.
4. Cap the samplers and pack securely for shipment.

SAMPLE PREPARATION:

5. Place the front and back sorbent sections of the sampler tube in separate vials. Discard the glass wool and foam plugs.
6. Add 1.0 mL eluent to each vial. Attach crimp cap to each vial.
7. Allow to stand 60 min with occasional agitation.

CALIBRATION AND QUALITY CONTROL:

8. Calibrate daily with at least six working standards over the range 0.01 to 10 mg acetic acid per sample.
   a. Add known amounts of acetic acid to eluent in 10-mL volumetric flasks and dilute to the mark.
   b. Analyze together with samples and blanks (steps 11 and 12).
   c. Prepare calibration graph (ratio of peak area of analyte to peak area of internal standard vs. mg acetic acid).

Figure 16–14. NIOSH Sampling Method 1603 provides guidelines for acetic acid sampling. (Reprinted from NIOSH *Manual of Analytical Methods,* 1994.) *(Continues)*

9. Determine desorption efficiency (DE) at least once for each batch of charcoal used for sampling in the calibration range (step 8). Prepare three tubes at each of five levels plus three media blanks.
   a. Remove and discard back sorbent section of a media blank sampler.
   b. Inject a known amount of acetic acid directly onto front sorbent section with a microliter syringe.
   c. Cap the tube. Allow to stand overnight.
   d. Desorb (steps 5 through 7) and analyze together with working standards (steps 11 and 12).
   e. Prepare a graph of DE vs. mg acetic acid recovered.
10. Analyze three quality control blind spikes and three analyst spikes to insure that the calibration graph and DE graph are in control.

MEASUREMENT:

11. Set gas chromatograph according to manufacturer's recommendations and to conditions given on page 1603-1. Inject sample aliquot manually using solvent flush technique or with autosampler.
    NOTE: If peak area is above the linear range of the working standards, dilute with formic acid, reanalyze and apply the appropriate dilution factor in calculations.
12. Measure peak area. Divide the peak area of analyte by the peak area of internal standard on the same chromatogram.

CALCULATIONS:

13. Determine the mass, mg (corrected for DE) of acetic acid found in the sample front (W_f) and back (W_b) sorbent sections, and in the average media blank front (B_f) and back (B_b) sorbent sections.
    NOTE: If $W_b > W_f/10$, report breakthrough and possible sample loss.
14. Calculate concentration, C, of acetic acid in the air volume sampled, V (L):

$$C = \frac{(W_f + W_b - B_f - B_b) \cdot 10^3}{V}, \text{ mg/m}^3.$$

EVALUATION OF METHOD:

Method S169 was issued on May 13, 1977 [3], and validated over the range 12.5 to 50 mg/m ^{3} at 22 °C and 767 mm Hg using a 173-L sample [1,4]. Overall precision, $\hat{S}_{rT}$, was 0.058 with an average recovery of 105.4%, representing a non-significant bias. The concentration of acetic acid was independently verified by a total hydrogen analyzer. Desorption efficiency was 0.96 in the range 2.1 to 8.4 mg per sample. Breakthrough (5% on back section) was never achieved and testing was discontinued after 4.6 hrs when 10.4 mg of acetic acid was collected without breakthrough for a 269-L sample at 90% RH. A user check gave an estimated LOD of 0.01 mg per sample and a desorption efficiency of 1.01 in the range 0.3 to 5 mg per sample [2].

REFERENCES:

[1] Backup Data Report for Acetic Acid, prepared under NIOSH Contract No. 210-76-0123, available as "Ten NIOSH Analytical Methods," Order No. PB 275-834 from NTIS, Springfield, VA 22161.
[2] User check, UBTL, NIOSH Sequence #4213-K (unpublished, January 31, 1984).
[3] NIOSH Manual of Analytical Methods, 2nd ed., V. 4, S169, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 78-175 (1978).

Figure 16–14. NIOSH Sampling Method 1603 provides guidelines for acetic acid sampling. (Reprinted from NIOSH *Manual of Analytical Methods,* 1994.) *(Continues)*

ACETIC ACID: METHOD 1603, Issue 2, dated 15 August 1994 - Page 4 of 4

[4] NIOSH Research Report-Development and Validation of Methods for Sampling and Analysis of Workplace Toxic Substances, U.S. Department of Health and Human Services, Publ. (NIOSH) 80-133 (1980).

METHOD REVISED BY:

G. David Foley and Y. T. Gagnon, NIOSH/DPSE; S169 originally validated under NIOSH Contract CDC-210-76-0123.

Figure 16–14. *(Concluded)*

make the analysis of the filter difficult. The maximum air sample volume is designed to minimize these problems.

Established maximum air sample volumes are designed to handle concentrations up to twice the exposure limit of a single contaminant. If the atmospheric concentration is well above twice the exposure limit or there are other interfering gases and vapors, saturation and breakthrough occur more quickly than anticipated. Maximum air sample volumes in these cases must be adjusted.

The flow rate specified in the air-sampling method provides the greatest collection efficiency for the chemical being sampled. For gases and vapors, it means that the analyte will be in contact with the absorbing or adsorbing material long enough to be captured. For particulates, it means that the particles will be effectively captured without damaging the collection device.

With the recommended flow rate and air sample collection volumes, the industrial hygienist can determine the time necessary to collect a sample. For example, if the recommended flow rate is 0.2 L/min and the minimum sample volume is 10 L, the sample time is at least 50 min. The formula is as follows:

$$\text{Required sample time (min)} = \frac{\text{Minimum sample volume (L)}}{\text{Flow rate (L/min)}} \quad (3)$$

$$\text{Required sample time} = \frac{10\,\text{L}}{0.2\,\text{L/min}} = 50\ \text{min} \quad (4)$$

Using the example above, it may be necessary, in this case, to use a series of samples to cover an eight-hour shift.

Laboratories require blanks for each set of samples submitted for analysis. The laboratory specifies the number and type of blanks needed. Two types of blanks may be used: a field blank or a media or lab blank. A field blank is a sample collection device that has been briefly opened and closed and is handled in the field identically to the other samples. The field blank is used to determine whether the air samples have been contaminated during handling. In contrast, a media blank is an *unopened* collection device used to determine whether the sampling collection device itself is contaminated.

CALIBRATION

The suction pumps used for air sampling must be calibrated to the airflow recommended in the sampling method. Calibration is critical because the determination of air sample volume depends on the flow rate and the elapsed time. There are two categories of calibration devices: primary and secondary. Primary devices provide a direct measurement of airflow. They include soap-bubble meters and spirometers. Secondary calibration devices provide indirect measurements of airflow and must be periodically calibrated with a primary calibration device. They include rotameters, wet test meters, and dry test meters.

Primary Calibration: Spirometer

The spirometer uses air displacement to measure air volume (Figure 16–15).

It is shaped like a cylindrical bell that contains a known volume of air with the open end sitting under a liquid seal. When the liquid is discharged, the air is displaced and forced out of the cylinder through the air-sampling instrument. The volume of air displaced is calculated based on the dimensions of the cylinder.

Primary Calibration: Soap-Bubble Meter

The most commonly used primary calibration instrument is the soap-bubble meter. It consists of an inverted volumetric burette connected to the sampling train. The sampling train must contain the type of collection device that will be used to conduct air sampling because each device causes a unique pressure drop. The pressure drop will affect the sampling pump's flow rate and must be accounted for during the calibration.

The general procedure for soap-bubble meter calibration is as follows:

1. Set up the apparatus as shown in Figure 16–16. Wet the inside of the burette with the soap solution or water before setup.

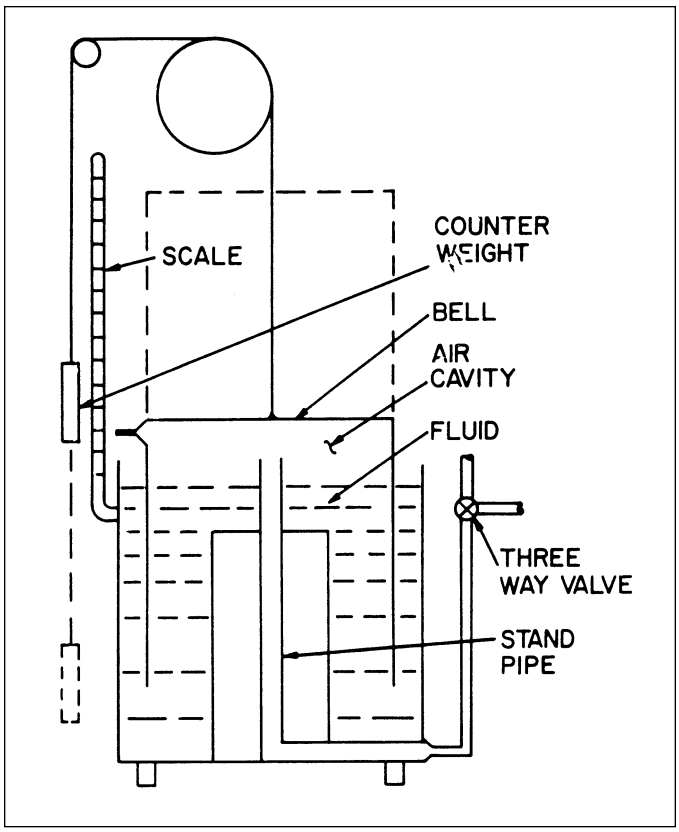

Figure 16–15. Schematic drawing of a spirometer. (Reprinted from Powell CH, Hosey AD, eds. *The Industrial Environment —Its Evaluation and Control*, 2nd ed. PHS Pub. no. 614, 1965.)

2. Allow the sampling pump to run for five minutes. Check the sampling pump's battery. If the battery is low, recharge the pump. Check the manufacturer's instructions for proper battery testing and recharging procedures.
3. Connect the sampling train to the burette.
4. To create a bubble, momentarily submerge the opening of the burette and then draw two or three bubbles up the length of the burette.
5. Adjust the pump to the nominal desired flow rate.
6. Create a soap bubble and, using a stopwatch, measure the time it takes to traverse a convenient calibration volume. For high-volume pumps, a 1,000-mL burette is used and the bubble is timed as it travels from 0 to the 1,000-mL mark. For low-flow pumps, a 100-mL burette is used.
7. Calculate the flow rate. The flow rate is determined by measuring the time required for the bubble to pass between two scale markings. For example, if 30 s were required for the bubble to go from the 0-mL to the 1,000-mL mark, then the flow rate is calculated as follows:

$$\frac{1{,}000\,\text{mL}}{30\ \text{s}} \times \frac{60\ \text{s}}{1\ \text{min}} = 2{,}000\ \text{mL/min or 2 L/min} \qquad (5)$$

8. If a different flow rate is desired, adjust the pump and repeat the procedure.

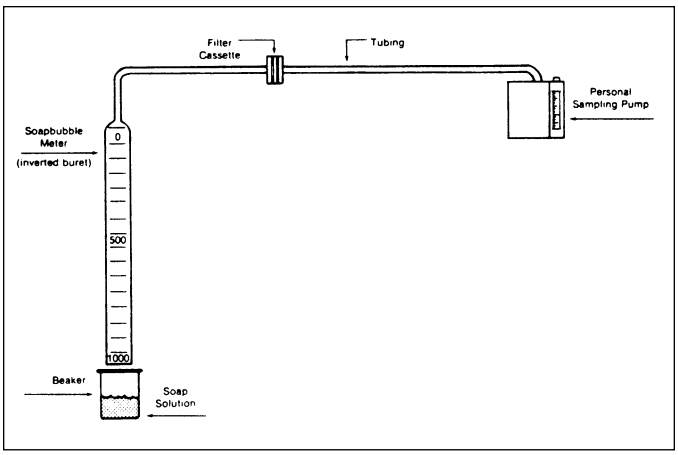

Figure 16–16. Calibration setup for personal sampling pump with filter cassette. (Reprinted from *OSHA Technical Manual,* 1995.)

9. Repeat the determination at least twice. Calculate the average flow rate.
10. Record the following:
    a. Volumes measured
    b. Elapsed times
    c. Air temperature
    d. Atmospheric pressure
    e. Make, model, and serial number of the sampling pump
    f. Collection device used
    g. Name and date of person performing calibration

Electronic soap-bubble meters (Figure 16–17) calibrate in less time and with greater accuracy than the traditional burette method. A microprocessor is used to time a bubble as it traverses from the first to the second sensor and to calculate the volume per unit time. The margin for error is supplied by the manufacturer and is typically ±0.5 percent.

Figure 16–17. Electronic soap-bubble meter provides calibration results quickly and accurately. Calibration information can be stored on a computer database. (Courtesy Gillian Instrument Corp.)

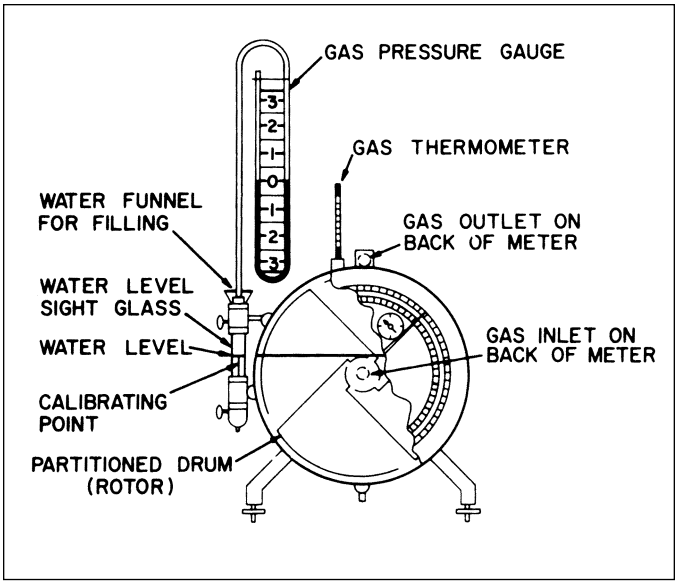

Figure 16–18. The working parts of a wet-test meter. (Reprinted from *The Industrial Environment—Its Evaluation and Control,* PHS Pub. no. 614, 1965.)

Secondary Calibration: Wet-Test Meter

A typical wet-test meter is a partitioned drum, half submerged in a liquid (usually water), with openings in the center and periphery of each radial chamber (Figure 16–18). Air or gas enters at the center and flows into one compartment, causing the chamber to rise and rotate. The number of revolutions made by the chamber is recorded on a dial. Because the liquid is replaced by air, the measured volume depends on the height of the fluid, so a sight gauge is provided. Temperature and pressure gauges are also provided.

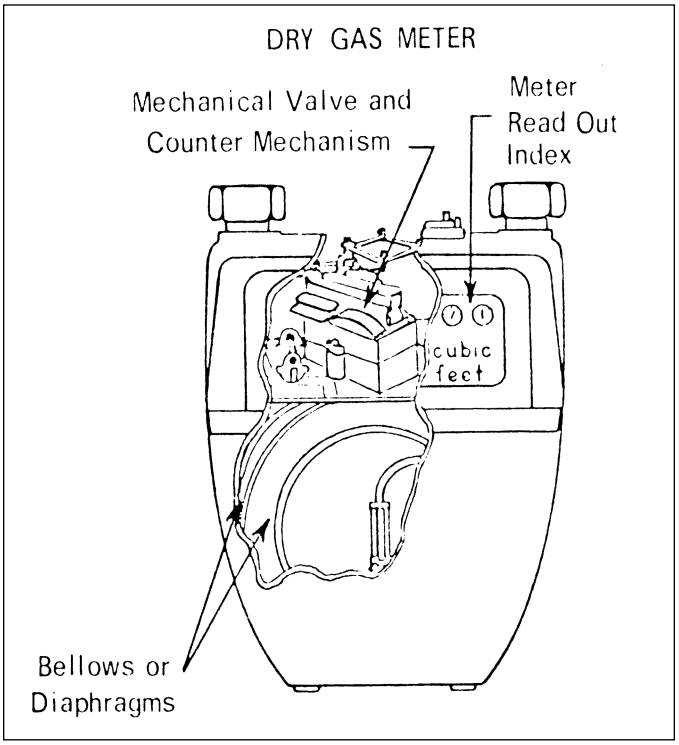

Figure 16–19. A dry-gas meter consisting of two bags connected by mechanical valves and a counting device. (Reprinted from *The Industrial Environment—Its Evaluation and Control,* PHS Pub. no. 614, 1965.)

Secondary Calibration: Dry-Gas Meter

A dry-gas meter, similar to a domestic gas meter, consists of two bellows connected by mechanical valves and a counting device (Figure 16–19). As air fills one bag, it mechanically empties another.

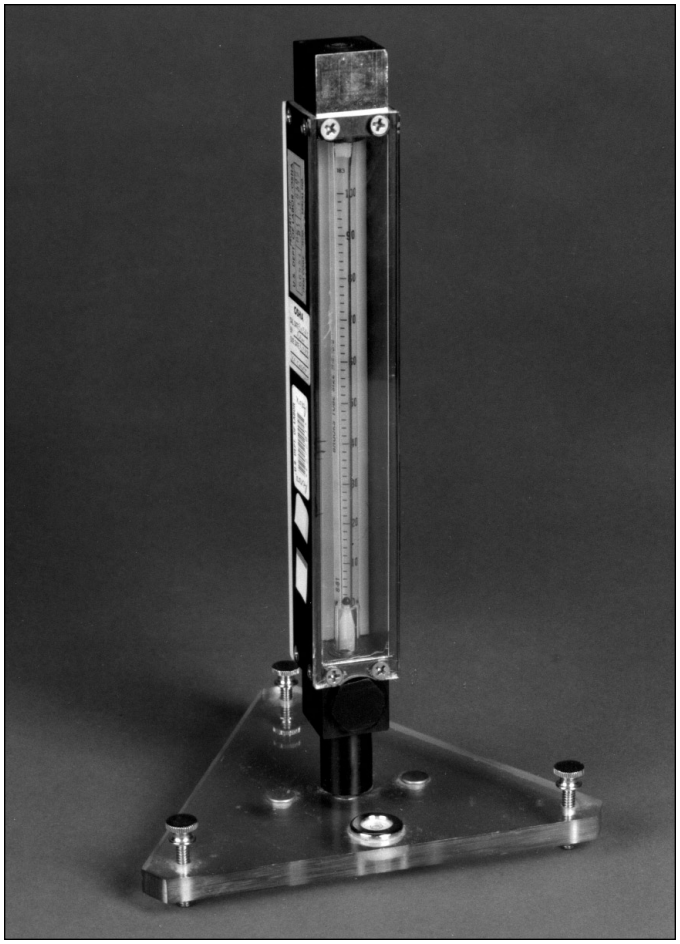

Figure 16–20. A single-column precision rotameter can be used as a secondary calibration device. (Courtesy Fermilab Visual Media Services Dept.)

Secondary Calibration: Precision Rotameter

A rotameter consists of a float, or ball that is free to move, in a vertically tapered tube (Figure 16–20).

Air is pulled through the tube so that the ball rises until there is an equilibrium between the force of gravity and the force of the air traveling upward. The flow rate is determined by reading the height of the float on an attached numerical scale. Rotameters are frequently used in the field to check pump flow rate periodically during full-shift sampling.

The rotameter's numerical scale has no meaning until it has been calibrated against a primary calibration device. A soap-bubble meter is usually used as the primary calibration device. First, an air-sampling pump is calibrated with the soap-bubble meter. Then a rotameter is attached to the sampling train (see Figure 16–21) to determine what scale marking relates to this flow rate. This is done several times so that a graph (see Figure 16–22) or chart of measured flow rate versus rotameter scale reading can be made. For rotameters used on a regular basis, this process should be repeated monthly.

Rotameters that are part of an air-sampling pump are not precision rotameters and should not be used for calibration purposes. They provide only an approximate indication of the airflow rate.

Calibration Parameters

TEMPERATURE AND PRESSURE

Air volume is directly affected by temperature and pressure. If the conditions during air sampling are significantly different from those during calibration, then a correction factor must be used when calculating the sample air volume (the field volume). This can be done using the following expression:

$$V_{field} = V_{calibration} \times \frac{T_{field}}{T_{calibration}} \times \frac{P_{calibration}}{P_{field}} \qquad (6)$$

where V_{field} = air sample volume in liters obtained during sampling period

$V_{calibration}$ = air sample volume in liters obtained by multiplying the calibrated airflow rate by the elapsed sampling time

T_{field} = absolute temperature during sampling in degrees Kelvin or Rankine

$T_{calibration}$ = temperature during calibration in degrees Kelvin or Rankine

$P_{calibration}$ = atmospheric pressure during calibration in mmHg or inches of water

P_{field} = atmospheric pressure during sampling in mmHg or inches of water

ERROR

The accuracy of calibration depends on the measuring limits of the equipment used. Each measuring instrument has a margin for error. This information can be obtained from the manufacturer.

Soap-bubble meter calibration, for example, uses a volumetric burette and a stopwatch. The burette may be accurate to within ±5 mL (or 5 percent); when the 1,000-mL mark is read, the true volume could be anywhere between 1,005 and 995 mL. Stopwatches have a similar margin for error.

The margin for error associated with the calibration of airflow rate can be calculated using the error of measurement from each piece of equipment used in the calibration, using the following equation:

$$\text{Error} = [(\text{instrument error})^2 + (\text{instrument error})^2]^{1/2} \qquad (7)$$

For the soap-bubble meter, for example, if the accuracy of the burette is 0.5 percent and the accuracy of the stopwatch is 0.5 percent, then the total margin for error is 0.7 percent. A calibrated flow rate of 2 L/min is more accurately reported as 2 L/min ±0.7 percent.

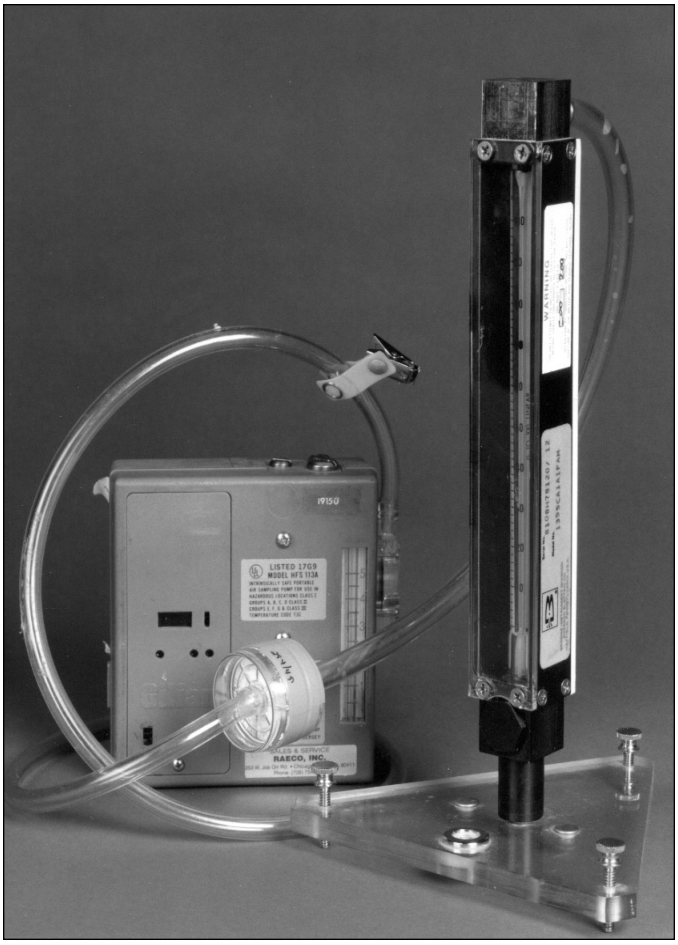

Figure 16–21. Precision rotameter connected to a sampling train. (Courtesy Fermilab Media Services Dept.)

SAMPLING TECHNIQUE

The instructions for air-sampling techniques are detailed in the Appendix to this chapter, which is reprinted from the 1998 *NIOSH Manual of Analytical Methods.*

SAMPLING AND ANALYTICAL ERROR

Once the air sample results are received from the analytical laboratory and the time-weighted averages are calculated, there should be a calculated margin of error associated with

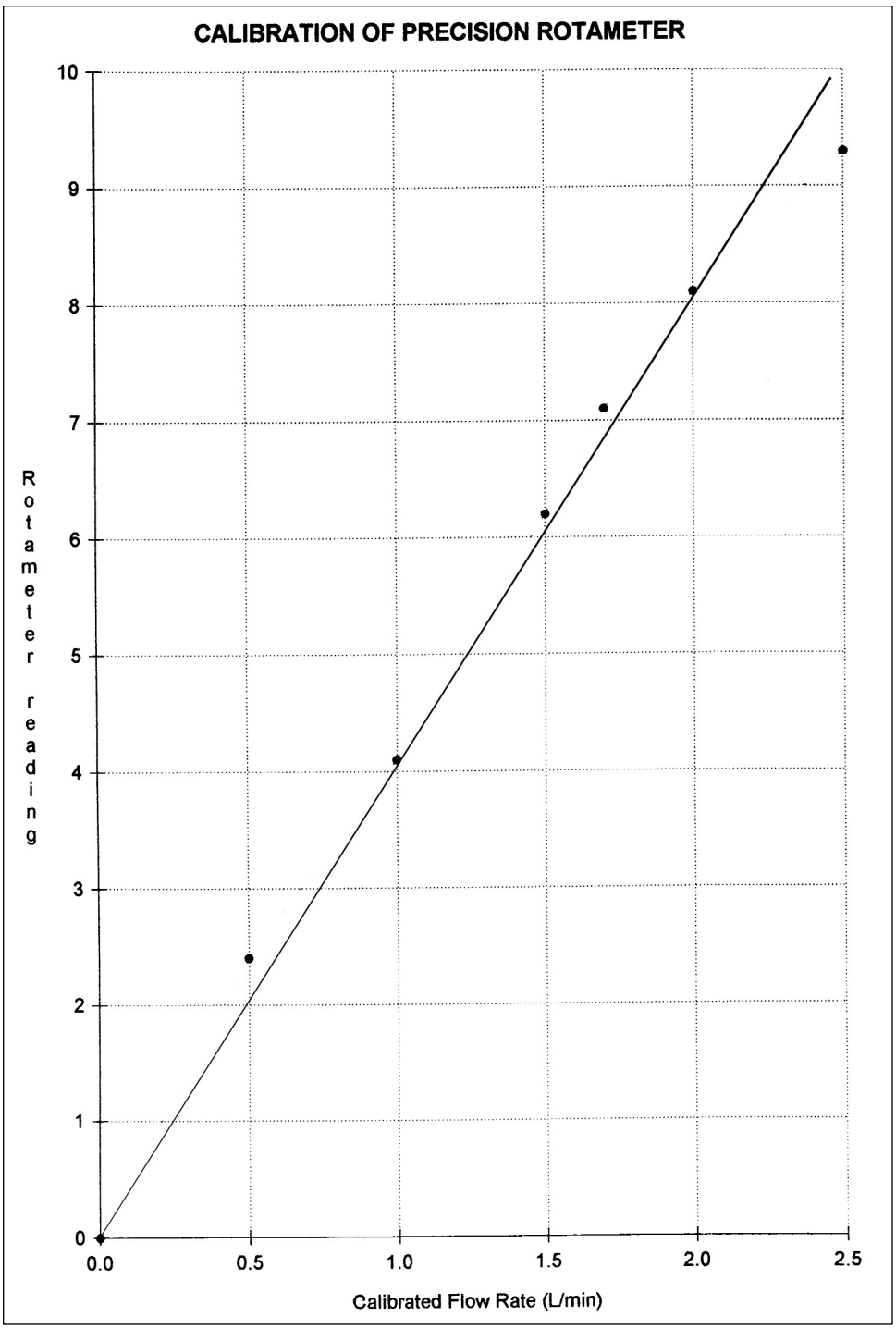

Figure 16–22. A calibration chart is needed when using a precision rotameter. The chart relates the rotameter's scale to a specific flow rate.

the results. This is called the sampling and analytical error (SAE), and can be calculated using the following formula:

$$\text{SAE} = [\,(\text{airflow error})^2 + (\text{time error})^2 + (\text{analytical error})^2\,]^{1/2} \quad (8)$$

The airflow error is the error of measurement associated with the calibration of the air-sampling pump. The time error is associated with the instrument used to measure the time period over which the sample was collected. The analytical error is the error associated with the analytical methods used by the laboratory.

RECORD KEEPING

Complete and detailed records must be kept on sampling procedures, sampling conditions, and sample results. The

Air Sampling Worksheet

U.S. Department of Labor
Occupational Safety and Health Administration

1. Reporting ID	2. Inspection Number	3. Sampling Number ▶ 0741041	
4. Establishment Name		5. Sampling Date	6. Shipping Date
7. Person Performing Sampling (Signature)		8. Print Last Name	9. CSHO ID
10. Employee (Name, Address, Telephone Number)		14. Exposure Information	a. Number / b. Duration / c. Frequency
		15. Weather Conditions	16. Photo(s) Y
11. Job Title	12. Occupation Code		
13. PPE (Type and effectiveness)		17. Pump Checks and Adjustments	

18. Job Description, Operation, Work Location(s), Ventilation, and Controls

Cont'd

19. Pump Number:

Sampling Data

20. Lab Sample Number						
21. Sample Submission Number						
22. Sample Type						
23. Sample Media						
24. Filter/Tube Number						
25. Time On/Off						
26. Total Time *(in minutes)*						
27. Flow Rate ☐ *l/min* ☐ *cc/min*						
28. Volume *(in liters)*						
29. Net Sample Weight *(in mg)*						

30. Analyze Samples for:

31. Indicate Which Samples To Include in TWA, Ceiling, etc. Calculations

32. Interferences and IH Comments to Lab

33. Supporting Samples
a. Blanks:
b. Bulks:

34. Chain of Custody	Initials	Date
a. Seals Intact?	Y N	
b. Rec'd in Lab		
c. Rec'd by Anal.		
d. Anal. Completed		
e. Calc. Checked		
f. Supr. OK'd		

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OSHA-91A (Rev. 1/84)

Figure 16–23. Air-sampling worksheet used by OSHA to record all pertinent information related to the collection of an air sample. ***(Continues)***

Pre-Sampling Calibration Records

pre					
	35. Pump Mfg. & SN	**38.** Flow Rate Calculations			
	36. Voltage Checked? ☐ Yes ☐ No				
	37. Location/T & Alt.				
		39. Flow Rate	**40.** Method ☐ Bubble ☐ PR	**41.** Initials	**42.** Date/Time

Post-Sampling Calibration Records

post			
	43. Location/T & Alt.	**44.** Flow Rate Calculations	
	45. Flow Rate	**46.** Initials	**47.** Date/Time

Sample Weight Calculations

48. Filter No.						
49. Final Weight *(mg)*						
50. Initial Weight *(mg)*						
51. Weight Gained *(mg)*						
52. Blank Adjustment						
53. Net Sample Weight *(mg)*						

54. Calculations and Notes:

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Figure 16–23. Air-sampling worksheet used by OSHA to record all pertinent information related to the collection of an air sample. ***(Concluded)***

hygienist must document that sampling was conducted according to accepted professional standards. Records should include the identity of the equipment and collection devices used, the calibration procedures and results, the identity of the analytical laboratory and related laboratory reports, and the air-sampling calculations.

The conditions under which the sampling was conducted should also be carefully documented to ensure the integrity and usefulness of the results. Anything that might help interpret or explain the final air sample result should be recorded. For example, in a production welding operation, the record should contain the name and location of the welder, the material being welded, the welding rods used, the number of pieces welded, the use of personal protective equipment, and the use and location of local exhaust ventilation.

Many industrial hygiene programs have developed air-sampling forms to ensure that all the necessary information is collected. OSHA has developed an air-sampling worksheet (Figure 16–23) for its Industrial Hygiene Compliance Officers.

OSHA Standard 29 *CFR* 1910.20, Access to Employee Exposure and Medical Records, requires that employee exposure records be preserved for at least 30 years. This information must be readily available to employees and their representative(s). Background data such as laboratory reports and field notes need only be retained for one year as long as information on the sampling method, the analytical and mathematical methods, and summary of other background information is retained for the required 30 years.

SUMMARY

Evaluating and controlling employee exposure to airborne occupational health hazards usually includes a comparison of the measured concentration of an airborne chemical to a recognized exposure limit. The various methods, instruments, and devices used for such air sampling have been described in this chapter.

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APPENDIX: NIOSH *METHODS FOR SAMPLING AIRBORNE* CONTAMINANTS

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McCammon CS, Woebkenberg ML. General considerations for sampling airborne contaminants in *Niosh Manual of Analytical Methods*, 5th ed.: pp 17–34, or www.cdc.gov/niosh.

D. GENERAL CONSIDERATIONS FOR SAMPLING AIRBORNE CONTAMINANTS

by Charles S. McCammon, Ph.D., CIH, NIOSH/Denver Field Office and
Mary Lynn Woebkenberg, Ph.D., NIOSH/DPSE

Contents:

1. CHOOSING MEASUREMENT METHODS AND SAMPLING MEDIA

Proper advance planning minimizes sampling and measurement costs and labor and contributes to a smooth, successful survey. Many things must be considered before collecting field samples [1]. The first step is to define sampling objectives. These may include documenting exposures in particular work settings, determining compliance/non-compliance with existing Federal or local standards or recommended exposure limits, or trying to determine the source of a problem. Sampling parameters that should be defined might include type of sample (area vs. personal), contaminant(s) to be sampled, duration of samples, potential interferences and expected contaminant concentrations (or contaminant concentration of interest). Once these parameters are defined, then the proper analytical method and sampling media can be selected. Other general information needed to plan a survey properly include the number of employees, the sampling strategy plan (discussed later), process flow diagram, material safety data sheets on all process materials, the physical states of the substances to be sampled, and potential hazards involved in collecting and shipping the samples.

An accredited analytical laboratory should be used to conduct analysis of collected samples, and it is essential to consult with the analytical laboratory before sampling to ensure that the measurement methods available can meet the defined sampling needs. This step should be an early part of survey planning. The laboratory can also assist in choosing sampling media

that are compatible with the sampling needs and the measurement methods available. The APPLICABILITY section of the individual methods in NMAM can be helpful in choosing which of the available methods is best for a particular situation.

Whether through consultation with the laboratory or through reading the specific measurement method, the sampling media will be specifically identified, e.g., pore size and type of filter, concentration and amount of liquid media required, and specific type and amount of solid sorbent (see Tables 1, 2 and 3 for common types, characteristics and behavior of sampling media). If specific brand name products are called for, no substitutions should be made. Most sampling media are well defined through research and testing; deviations from specifications are undesirable. For example, most organic contaminants are sampled with a dual section tube containing 100 mg front and 50 mg backup sections of 20/40 mesh activated coconut shell charcoal. If larger mesh charcoal or a different type of charcoal were to be used, the sampling capacity and recovery efficiencies for the contaminant of interest might change from that specified in the method.

The physical state of the contaminant(s) being sampled may also be a factor in determining the media required. In the case of polyaromatic hydrocarbons (PAHs), for example, the proper sampler consists of a membrane filter to trap particulate matter and a solid sorbent tube to trap the vapors of certain PAHs so that total collection is assured.

The sampling pump used to collect the sample must also be compatible with the sampling needs and the media used. Specifically, the pump must be capable of maintaining the desired flow rate over the time period needed using the sampling media specified. Some pumps may not be able to handle the large pressure drop of the media. This will be true for fine mesh (smaller than 40 mesh) solid sorbent tubes, small pore size filters or when attempting to take a short-term sample on a sorbent tube of a higher than normal pressure drop at a flow rate of 1 L/min or greater. As a rule of thumb, all high flow pumps (1 to 4 L/min) can handle at least 3 kPa (12 inches of water) pressure drop at 1 L/min for 8 h. Some pumps can handle up to 7.5 kPa (30 inches of water) pressure drop at flows up to 2 or 3 L/min. Most low flow pumps (0.01 to 0.2 L/min) can handle the pressure drops of available sorbent tubes without problems except that the nominal flow rate may decrease for certain models. All pumps should be calibrated with representative sampling media prior to use. It is good practice to check the pump calibration before and after use each day. As a minimum, calibration should be done before and after each survey.

TABLE 1. TYPES AND USES OF SOLID SORBENTS [2]*

Activated charcoal

By far the most commonly used solid sorbent. Very large surface area:wt. ratio. Reactive surface, high adsorptive capacity. This surface reactivity means that activated charcoal is not useful for sampling reactive compounds (e.g., mercaptans, aldehydes) because of poor desorption efficiency. The high capacity, however, makes it the sorbent of choice for those compounds which are stable enough to be collected and recovered in high yield. Breakthrough capacity is a function of type (source) of the charcoal, its particle size and packing configuration in the sorbent bed. Humidity may affect the adsorption as well.

Silica gel

Less reactive than charcoal. Because of its polar nature, it is hygroscopic and shows a decrease in breakthrough capacity for non-water soluble substances with increasing humidity [3].

Porous polymers

Lower surface area and much less reactive surface than charcoal. Adsorptive capacity is, therefore, generally lower, but reactivity is much lower as well.

Ambersorbs™

Properties midway between charcoal and porous polymers.

Coated sorbents

One of the sorbents upon which a layer of a reagent has been deposited. The adsorptive capacity of such systems usually approaches the capacity of the reagent to react with the particular analyte [4].

Molecular sieves

Zeolites and carbon molecular sieves retain adsorbed species according to molecular size. A limiting factor is that the water molecule is of similar size to many small organic compounds and is usually many orders of magnitude higher in concentration than the species of interest. This unfavorable situation may result in the displacement of the analyte by water molecules. Drying tubes may be used during sampling to eliminate the effects of humidity [5].

Thermal desorption

Thermal desorption tubes may contain several different sorbents in order to collect a wide range of different chemicals [6]. These tubes are generally used in situations where unknown chemicals or a wide variety of organics are present, e.g., in indoor environmental air quality investigations. Analysis is often by gas chromatography/mass spectrometry (GC/MS).

***NOTE:** Solid sorbents are used for the collection of vapors only. Aerosols are not collected effectively by most sorbent beds, but may be collected by other components of the sampler (e.g., a prefilter, or the glass wool plugs used to hold the sorbent bed in place).

TABLE 2. TYPES AND USES OF AEROSOL SAMPLERS [6]

Membrane filters

By far the most frequently used filters. This class of filters includes those made from polyvinyl chloride, Teflon®, silver, and mixed cellulose esters. Filters from this class are used for sampling asbestos, minerals, PAHs, particulates not otherwise regulated, and elements for ICP analysis.

Glass and quartz fiber filters

Quartz filters have replaced glass in many applications. They are used in applications such as sampling for mercaptans and diesel exhaust.

Polycarbonate straight pore filters

Because of their characteristics, these filters are good for the collection of particles to be analyzed by electron microscopy and x-ray fluorescence.

Respirable dust samplers

The 10-mm nylon cyclone and (preferably) conductive cyclones with a 50% cut at 4 µm are used with polyvinyl chloride filters to collect various forms of silica.

Inhalable dust samplers

The Institute of Occupational Medicine's (IOM) sampler is used, in conjunction with a polyvinyl chloride filter, for sampling formaldehyde on dust [7].

TABLE 3. FACTORS AFFECTING THE COLLECTION OF GASES, VAPORS, and AEROSOLS [2, 7]

Temperature

Since all adsorption is exothermic, adsorption is reduced at higher temperatures. Additionally, if there is a reaction between an adsorbed species and the surface, or between two or more adsorbed species (e.g., hydrolysis or polymerization), the rate of such reactions increases at higher temperatures.

Temperature stability of a filter must be considered when sampling hot environments such as stack effluents.

Humidity*

Water vapor is adsorbed by polar sorbents; their breakthrough capacity for the analyte is thereby reduced for most organic compounds. However, for water soluble compounds, the breakthrough capacity is increased, e.g., chlorine and bromine [8] and formaldehyde [3]. This effect varies from substantial for more polar sorbents, such as charcoal and silica gel, to a smaller effect for Ambersorbs™ and porous polymers.

Filter media may also be affected by humidity. Moisture may affect a filter's collection efficiency. Very low humidities (#10% RH) may make some filters (e.g., cellulose ester) develop high charge levels, causing non-uniform deposits and repulsion of particles [9]. Water absorption by some filters (e.g., cellulose ester) can cause difficulty in obtaining tare weights for gravimetric analysis.

Sampling flow rate*/ Face velocity

Breakthrough volume of a solid sorbent bed tends to be smaller at higher sampling flow rates, particularly for coated solid sorbents. For sorbents such as charcoal whose breakthrough capacity for most organic compounds can be significantly reduced by high humidity, lower sampling flow rates may actually result in smaller breakthrough volumes [10]. The collection efficiency of filters will change with face velocity.

Concentration*

As the concentration of contaminant in air increases, breakthrough capacity (mg adsorbed) of a solid sorbent bed increases, but breakthrough volume (L of air sampled) decreases [10].

Particle Characteristics

Filter collection efficiency is a function of pore size [11]. Particles smaller than about 0.2 µm are collected primarily by diffusion, while particles larger than about 0.2 µm are collected primarily by impaction and interception. Most sampling filters are highly efficient ($95%) for all particle sizes, with the minimum efficiency in the 0.2 µm size range. Polycarbonate straight pore filters exhibit poor collection by diffusion, so particles smaller than the pore size are not collected efficiently.

Filter considerations

The pressure drop of a filter can limit the sampling time, because of the load on the personal sampling pump. In addition, pressure drop increases with dust loading on the filter. Fine particles (#0.5 µm) will increase the pressure drop much faster than coarse particles ($10 µm). Heavy loading ($ about 1 mg) may result in poor adhesion of collected particles to the filter surface.

***NOTE**: It is important to distinguish between equilibrium (saturation) adsorptive capacity and kinetic (breakthrough) adsorptive capacity of the solid sorbent. Breakthrough capacity is the important characteristic in actual sampling situations; it may be affected significantly by sampling flow rate and relative humidity of the air being sampled and may be significantly less than saturation capacity, which is not dependent on sampling flow rate or relative humidity.

2. FIGURING SAMPLING PARAMETERS

Once the sampling media and measurement method are chosen, then the specific sampling parameters need to be determined [12]. For most methods, this will not pose a problem as the flow rate recommended in the method can be used for the desired sampling period, e.g., 1 to 3 L/min for 8 h for most aerosols or 10 to 200 mL/min for 8 h for most sorbent tube samples. Generally, the parameters which must be considered are flow rate, total sample volume, sampling time (tied into the two previous parameters), and limit of quantitation (LOQ) (see Glossary of Abbreviations, Definitions and Symbols). Some of these variables will be fixed by sampling needs, e.g., sampling time or by the measurement method of choice (LOQ or maximum sampling volumes). The choice of these variables can best be explained through the use of the following examples.

Examples:

a. **Sampling for Gases and Vapors Using Solid Sorbents**

Given parameters:	Method 1501 for Styrene
Recommended Sample Volume:	5 L
Useful Range of the Method:	85 to 2560 mg/m^3 (20 to 600 ppm)
OSHA PEL:	850 mg/m^3 (200 ppm) - Ceiling
	425 mg/m^3 (100 ppm) - TWA
Recommended Flow Rate:	0.2 L/min
Breakthrough Time:	111 min @ 0.2 L/min and 1710 mg/m^3
Breakthrough Capacity	38 mg

Suppose it is desired to determine both ceiling and TWA exposures of workers exposed to styrene and the concentrations are unknown.

Ceiling Determination: If sampling were done at 0.2 L/min for 30 min and a total sample volume of 6 L collected which is above the 5 L recommended sample volume, would this a problem? Probably not. For instance, in the breakthrough test, a concentration of 2 times the OSHA Ceiling Standard (1710 mg/m^3) was sampled at 0.2 L/min for 111 min (22.2 L) before breakthrough occurred, collecting a total weight of 38 mg of styrene. Of course, this test was conducted in a dry environment with only styrene present. A safety factor of 50% should be allowed to account for humidity effects. Thus, if sampling is done for about 55 min at 0.2 L/min, levels of styrene up to 400 ppm could still be collected without sample breakthrough.

Also to be considered are the other organics present. If a concentration of 200 ppm acetone exists in this environment, then an additional safety factor should be added. An arbitrary 50% reduction in total sampling time or 28 min at 0.2 L/min might be done. This is very close to the original sampling time of 30 min. With the safety factors built in, collecting a 6-L sample should not be a problem. Alternately, the flow could be reduced to 0.1 L/min and be well within the 5-L total volume.

TWA Determination: In this same situation, the goal is to collect 8-h samples for comparison to the 100 ppm TWA. If sampling were done at 0.05 L/min, then the total sample volume would be 22.5 L, substantially above the 5-L recommended sample volume. If the flow was dropped to 0.02 L/min, then the sample volume would be 9 L. This sample volume might be acceptable if the styrene concentrations are around 100 ppm and no other competing organics are present, e.g., acetone. However, the safer approach would be to collect two consecutive samples at 0.02 L/min for 4 h (total sample volume of 4.8 L each).

b. **Pushing a Method to the Limit, Limit of Quantitation**

Given Parameters:	Method 1009 for Vinyl Bromide (VB)
Recommended Sample Volume:	<10 L @ 0.20 L/min or less
Working Range:	0.3 to 33 ppm (1.3 to 145 mg/m^3) for a 6-L air sample; this equals 8 to 355 µg VB per tube
Limit of Detection:	3 Fg VB per tube

In this particular example, let us say that the object is to estimate exposure to vinyl bromide down to 0.1 ppm (0.44 mg/m^3), which is below the working range. In order to collect 8 µg of vinyl bromide (the limit of quantitation) at this concentration, 20 L of air will have to be collected. This volume is substantially above the maximum recommended sample volume of 10 L. Since the recommended sample volume is generally a conservative value used to protect against breakthrough under worst case conditions (i.e., high humidity and high concentrations), considerable leeway exists for the size of the air sample. In this example, the 20-L air samples should be taken at 0.2 L/min or slower, and the possibility of breakthrough should be monitored by observing the relative amounts of analyte on the backup sections of the samples.

The best approach is to consult with the analytical laboratory and then to take a sufficient number of samples to determine the useful limits of the sampler in the particular application. The presence of high relative humidity and other organic solvents will severely reduce the number of active sites available on the sorbent for collection of the contaminant of interest. In pushing a method to the limit, it is often necessary to sample beyond the breakthrough volume, while observing recommended maximum sampling flow rate, in order to obtain the sensitivity to determine the concentration of interest. If this is done, then the risk must be accepted that the method may not work outside the limits tested.

c. **Sampling for Dusts Using a Membrane Filter**

Given parameters:	Method 7401 for Alkaline Dusts
Recommended Sample Volume:	70 L @ 2 mg/m^3; 1000 L max.
Useful Range of the Method:	0.76 to 3.9 mg/m^3
OSHA PEL:	2 mg/m^3 (NaOH)
Recommended Flow Rate:	1 to 4 L/min

Suppose it is desired to determine both an exposure taking place during a specific 20 minute operation as well as a TWA exposure of workers exposed to sodium hydroxide and the concentrations are unknown.

20 Minute Process Sample: This sample would meet the method conditions by sampling for the 20 minutes at 4 L/min since this would collect 80 L. Sampling at 1, 2, or 3 L/min for 20 minutes would probably not allow for the collection of sufficient sample required for analysis.

TWA Determination: In this situation, it is necessary to collect an 8-h sample to compare with the 2 mg/m^3 OSHA PEL. Since an 8-h TWA sample covers 480 minutes, sampling can no longer be done at 4 L/min since this would collect 1920 L, almost twice the upper recommended sample volume. Sampling at 1 L/min would collect a 480 L sample, and sampling at 2 L/min would collect a 960 L sample, both acceptable per the conditions of the method.

3. BULK SAMPLES

The addition of bulk samples can often make the difference between a successful or unsuccessful sampling effort. This is especially true where there is mixed solvent exposure or unknown dust exposure and for determining silica content of dusts. The primary purpose of bulk samples is to provide the analytical laboratory with a large enough sample for qualitative and sometimes quantitative analysis. The two major types of bulk samples are bulk air and mass bulk (liquid or solid) samples.

a. **Bulk Air Samples**

Generally, a bulk air sample is defined as a large volume area sample collected for the purpose of qualitative analysis. A good example is multiple solvent exposure where the exact identity of the airborne solvents is unknown, e.g., painting operations. For most organic solvents, a bulk air sample consists of a charcoal tube (or whatever sorbent is called for) collected at 1 L/min for an hour or more. Although the sample is likely to exhibit breakthrough, this does not matter since one is primarily interested in what substances are present rather than their exact concentrations (the latter aim is accomplished through the separate collection of proper samples). Any questions concerning how or whether or not a bulk air sample is needed should be addressed to the analytical laboratory prior to sampling. In the case of silica, either a bulk air or solid bulk sample (e.g., a rafter sample) or both are suggested so that enough material will be available to determine free silica content.

b. **Bulk Liquids and Solids**

Collection of bulk materials may be needed to establish the substances present in the workplace and, in some cases, to establish the relative levels of certain substances present in the raw material. A good example of the latter is the case of mixed solvent exposure when determining if a certain contaminant of interest is present, e.g., benzene. In some cases, a list of 30 solvents may be present (from Material Safety Data Sheets), but it is not certain which ones are present or in what proportions. This example is also true for dusts, as was discussed previously for silica, or for metals which may exist in trace quantities.

In choosing bulk samples, the end goal must be considered: qualitative and/or quantitative analysis. In the case of a painting operation, it is preferred to have the bulk samples separated by contaminants of interest, i.e., solvent fraction separate from the pigment fraction. This allows the laboratory to analyze the different portions of the paints without having to go through a lengthy separation process. In general, the cleaner the bulk, the easier it will be for the laboratory to conduct the analysis. In many cases, the industrial hygienist is interested in a "dirty" bulk. Any information that can be given to the laboratory on what may or may not be present will help speed up the analysis. Advance consultation with the laboratory is desirable.

In choosing bulk dust samples, the sample should be representative of the airborne dust to which the workers are being exposed. Usually this is a settled dust sample collected from rafters or near the workers' job site. In other cases, a process dust sample is chosen to determine the composition of the material before it is airborne. In cases where the choice is not clear, do not follow the adage that "more is better." Bulk samples should be limited in number to optimize the laboratory's time. A good approach, when in doubt as to what bulks are needed, is to collect several but to allow the laboratory to analyze only those needed to answer questions as they arise.

When shipping bulks, care must be taken to preserve the integrity of the samples and to follow established Department of Transportation (DOT) shipping regulations. Only 5 to 10 mL of the liquid or solid is needed, so keep bulk sample sizes small. In general, leak-proof glass containers are best since they will not react with most chemicals; however, polyethylene containers can be used in the majority of cases. A convenient container is a 20-mL scintillation vial with PTFE-lined cap. Specific chemicals for which polyethylene containers should not be used include aromatic compounds, chlorinated hydrocarbons and strong acids. The lids of the containers should be sealed with shrink bands or tape for further assurance against leakage. These containers should be labeled as required by DOT under their regulations, 49CFR Part 171-177. For most materials classified as "Flammable" or "Poisonous," amounts up to 1 quart can be shipped by any carrier. Most bulk dusts are not covered by DOT regulations. Specific restrictions and labeling requirements should be checked prior to shipping any samples.

In the case of volatile bulk samples (and some air samples), consideration should be given to shipping the samples on dry ice or with bagged refrigerant (e.g., "blue ice"). Do not ship volatiles together with air samples. Again, check with the carrier you plan to use as there

may be restrictions on the amount of dry ice they will accept in a package (usually 5 pounds or less is acceptable). Specific labels are usually required when dry ice is used.

4. BLANKS

Certain numbers of blanks are required by the analytical laboratory for each set of samples to be analyzed. The specific method being used should be consulted concerning the number and type of blanks required. There are two types of sampler blanks: field and media blanks. Field blanks are clean samplers taken to the sampling site, handled in every way as the air samples, except that no air is drawn through them. Media blanks are simply unopened, new samplers which are sent with the samples (these blanks are not usually taken to the field). It is also recommended that additional blind field blanks be sent along with the field samples, labeled as field samples, as a further check on the analysis. Blanks are good insurance to deal with contamination, but the best approach is to avoid sample contamination by being careful. The recommended practice for the number of field blanks is two field blanks for each 10 samples with a maximum of 10 field blanks for each sample set. Media blanks should also be included. These unexposed, unopened samplers will give an estimate of media background. The laboratory should analyze at least six (6) media blanks from the same lot as the field samples. This number should be increased for media which are coated or impregnated with reagent. Again, consult the specific method for the number and type of blanks as these numbers will vary.

Another frequently-used practice is to include blind spiked samples as a quality control check of the analytical laboratory. See the following chapter for a detailed discussion of spiking procedures.

5. DIRECT-READING METHODS

The variety of types of direct-reading methods available is large and expanding, including detector tubes (both short- and long-term), aerosol monitors, integrating passive monitors for certain gases and portable instrumentation for gas chromatography or infrared spectroscopy [13]. Many direct-reading instruments now used for personal or area measurements have evolved from laboratory or process control instruments [14].

Some of the considerations (i.e., specificity and sensitivity) for the use of direct-reading methods for quantitative determinations are similar to those already given for classical filter or sorbent methods. In many cases, direct-reading instruments, which are physically small and portable, qualify as personal sampling devices.* These offer the additional advantages over classical methods by reducing labor and analytical costs and may be the methods of choice when instantaneous results are important, even at the expense of some degree of sensitivity or specificity. In general, manufacturers' instructions should be followed in the calibration and use of these devices. Because of the severe conditions to which direct-reading instruments may be subjected, performance checks and preventive maintenance on a periodic basis or before each use are very important. Many direct-reading instruments are powered by Ni-Cd batteries which can fail to provide a full charge over the full sampling period unless frequently or fully discharged and recharged several

times just prior to use. An additional responsibility, that of field calibration of the direct-reading instrument, falls on the field sampling personnel.

***NOTE:** A portable instrument is defined as weighing less than 4.5 kg (10 lbs.) and powered by self-contained batteries [15]. For personal monitoring, the instrument configuration should be such that the breathing zone can be monitored. Alarms, both audible and visual, and hard-copy documentation are desirable.

6. SAMPLING STRATEGY

To obtain the maximum amount of information during the course of a survey with a minimum number of samples, a statistical sampling strategy should be developed before conducting any survey [16]. Several pieces of information must be known in advance to plan a sampling strategy, including the size of the workforce to be sampled, the accuracy of the sampling and measurement method to be used and the confidence one wishes to have in predicting the exposure of the workforce.

For example, to determine with 90% confidence that at least one worker from a workplace subgroup will be in the top 10% of the exposures occurring in the group, the number of employees to sample would be chosen from Table 4. Other tables are given in the publication for confidence limits of 95% and for the top 20% of exposures. Again, judicious use of sampling statistics will optimize the number of samples needed.

Table 4. Minimum sample size (n) for including (@ 90% confidence level) at least one high risk employee* [16]

Size of Employee Group (N):	1	2	3	4	5	6	7	8	9	10	11-12	13-14	15-17	18-20	21-24	25-29	30-37	39-49	50	4
Minimum Number of Measured Employees (n):	1	2	3	4	5	6	7	7	8	9	10	11	12	13	14	15	16	17	18	22

*Exposure in highest 10% of N.

7. SAMPLING AND CALIBRATION TECHNIQUES

The following are suggested general techniques for active sampling using some of the more common samplers. These instructions elaborate on those given in NMAM methods. Consult individual methods for details of sample size.

7. SAMPLING AND CALIBRATION TECHNIQUES

The following are suggested general techniques for active sampling using some of the more common samplers. These instructions elaborate on those given in NMAM methods. Consult individual methods for details of sample size.

a. **Calibration of Personal Sampling Pumps**

The accuracy of determinating the concentration of a toxic substance in air is no greater than the accuracy with which the air volume is measured. Therefore, accurate calibration of the airflow rate through the sampling train is necessary. The frequency of calibration depends on the use, care and handling to which the pump is subjected. In addition, pumps must be recalibrated after each repair and if they have been abused. Ordinarily, pumps should be calibrated in the laboratory and the field, both before field use and after each field survey.

The choice of a reference instrument will depend on where the calibration is to be performed. For laboratory use, primary standards, such as a spirometer or soap-bubble meter, are recommended [17]. Several electronic soap-bubble calibrators and one dry-cell calibrator are commercially available as primary calibrators. Other instruments, such as a wet-test, mass-flow or a dry-gas meter, may be used. The following instructions are for the soap-bubble meter. If another instrument is used, equivalent procedures should be followed.

(1) Set up the apparatus as shown in Figure 1.

(2) Make certain that the rechargeable batteries will power the pump for the entire sampling interval by one of the following methods: 1) run the pump for that length of time, checking for satisfactory operations; 2) test the battery independently of the pump using a current capacity tester [17]. Fully recharge the batteries.

(3) Turn the pump on and moisten the inner surface of the soap-bubble meter with the soap solution. Draw bubbles upward until they travel the entire length of the buret without breaking.

(4) Adjust the pump to the desired nominal flow rate. Check the water manometer. The pressure drop across the sampler should not exceed 2.5 cm Hg (13 inches) of water.

(5) Start a soap bubble in the buret and measure the time, with a stopwatch, that it takes to traverse two calibration marks. For a 1000-mL buret, a convenient calibration volume is 500 mL. Repeat the determination at least twice more. Average the results and calculate the flow rate by dividing the calibration volume by the average time.

(6) Record the following data:
   a. volume measured
   b. elapsed time
   c. pressure drop
   d. air temperature
   e. atmospheric pressure
   f. serial number of the pump
   g. pump model
   h. date and name of operator

(7) If the sampling pump used for sample collection uses a variable area flow meter (rotameter) for flow rate indication, the calibrated flow rate must be adjusted for the actual air pressure and temperature during sampling [18]. The expression for this correction is as follows.

NOTE: This correction is **not** used for non-rotameter sampling pumps.

$$V \text{ (Corrected volume, L)} = Q\ t\ (P_c T_s / P_s T_c)^{0.5}$$

where:
- Q = indicated flow rate (L/min)
- t = sampling time (min)
- P_c = pressure during calibration of sampling pump (kPa or other pressure units)
- P_s = pressure of air sampled (same units as P_c)
- T_c = temperature during calibration of sampling pump (EK)
- T_s = temperature of air sampled (EK).

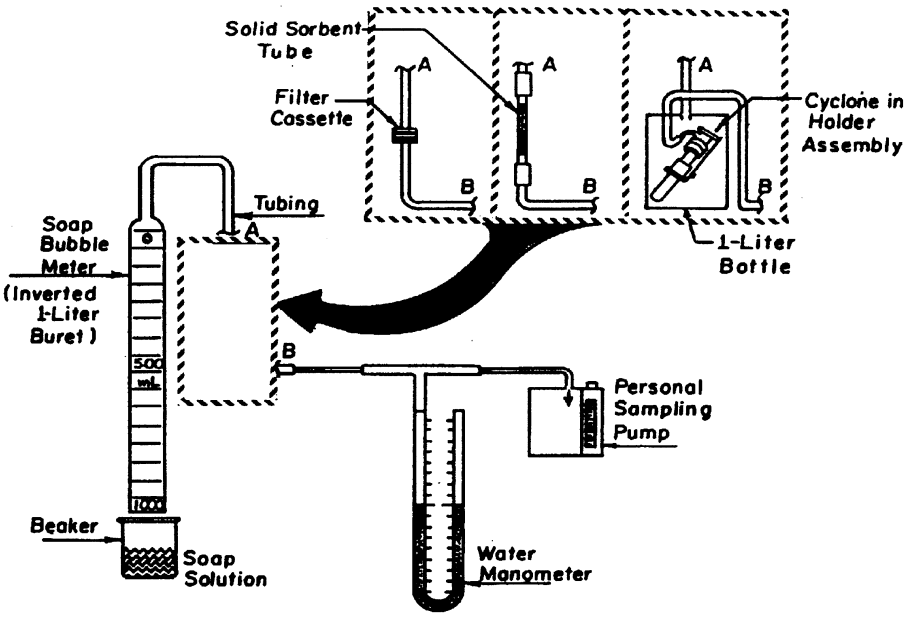

Figure 1. Calibration Apparatus.

b. **Sampling Instructions for Solid Sorbent Tube Sampler**

Use these instructions for active personal sampling (i.e., pumped sample airflow) for substances which are retained on solid sorbents such as activated charcoal, silica gel, porous polymers, etc.

(1) Calibrate each personal sampling pump at the desired flow rate with a representative solid sorbent tube in line (alternatively, use a flow restrictor to provide a pressure drop equal to that of the average solid sorbent tube). Use a bubble meter or equivalent flow measuring device.

(2) Break the ends of the solid sorbent tube immediately before sampling to provide an opening at least one-half of the internal diameter at each end.

(3) Connect the solid sorbent tube to a calibrated personal sampling pump with flexible tubing with the smaller sorbent section (backup section) nearer to the pump. Do not pass the air being sampled through any hose or tubing before entering the solid sorbent tube. Position the solid sorbent tube vertically during sampling to avoid channeling and premature breakthrough.

(4) Prepare the field blanks at about the same time as sampling is begun. These field blanks should consist of unused solid sorbent tubes from the same lot used for sample collection. Handle and ship the field blanks exactly as the samples (e.g., break the ends and seal with plastic caps) but do not draw air through the field blanks. Two field blanks are required for each 10 samples with a maximum of 10 field blanks per sample set.

(5) Take the sample at an accurately known flow rate as specified in the method for the substance and for the specified air volume. Typical flow rates are in the range 0.01 to 0.2 L/min. Check the pump during sampling to determine that the flow rate has not changed. If sampling problems preclude the accurate measurement of air volume, discard the sample. Take two to four replicate samples for quality control for each set of field samples.

(6) Record pertinent sampling data including location of sample, times of beginning and end of sampling, initial and final air temperatures, relative humidity and atmospheric pressure or elevation above sea level.

(7) Seal the ends of the tube immediately after sampling with plastic caps. Label each sample and blank clearly with waterproof identification.

(8) Pack the tubes tightly with adequate padding to minimize breakage for shipment to the laboratory. In addition to the sample tubes and field blanks, ship at least six unopened tubes to be used as media blanks so that desorption efficiency studies can be performed on the same lot of sorbent used for sampling.

(9) Ship bulk samples in a separate package from the air samples to avoid contamination of the samples. Suitable containers for bulk samples are glass with a polytetrafluoroethylene (PTFE)-lined cap, e.g., 20-mL glass scintillation vials.

c. **Sampling Instructions for Filter Sampler**

Use these instructions for personal sampling of total (respirable and non-respirable) aerosols. Methods requiring these instructions specify FILTER as the sampling method. These instructions are not intended for respirable aerosol sampling.

(1) Calibrate the personal sampling pump with a representative filter in line using a bubble meter or equivalent flow measuring device.

(2) Assemble the filter in the two-piece cassette filter holder. Support the filter by a cellulose backup pad or stainless steel screen. Close the cassette using a press

[19] or other technique that ensures cassette parts mate evenly and positively to prevent leakage. Seal the filter holder with plastic tape or a shrinkable cellulose band to reduce contamination during filter removal.

(3) Remove the filter holder plugs and attach the filter holder to the personal sampling pump with a piece of flexible tubing. Clip the filter holder to the worker's lapel. Air being sampled should not be passed through any hose or tubing before entering the filter holder.

(4) Prepare the field blanks at about the same time as sampling is begun. These field blanks should consist of unused filters and filter holders from the same lot used for sample collection. Handle and ship the field blanks exactly as the samples, but do not draw air through the field blanks. Two field blanks are required for each 10 samples with a maximum of 10 field blanks per sample set.

(5) Sample at a flow rate of 1 to 3 L/min until the recommended sample volume is reached. Set the flow rate as accurately as possible (e.g., within ± 5%) using the personal sampling pump manufacturer's directions. Take two to four replicate samples for quality control for each set of field samples.

(6) Observe the sampler frequently and terminate sampling at the first evidence of excessive filter loading or change in personal sampling pump flow rate. (It is possible for a filter to become plugged by heavy particulate loading or by the presence of oil mists or other liquids in the air.)

(7) Disconnect the filter holder after sampling. Cap the inlet and outlet of the filter holder with plugs. Label the sample. Record pertinent sampling data including times of beginning and end of sampling, initial and final air temperatures, relative humidity and atmospheric pressure or elevation above sea level. Record the type of personal sampling pump used and location of sampler.

(8) Ship the samples to the laboratory as soon as possible in a suitable container designed to prevent damage in transit. Ship bulk material to the laboratory in a glass container with a PTFE-lined cap. Never store, transport or mail the bulk sample in the same container as the samples or field blanks. In addition to the samples and field blanks, ship five unopened samplers from the same lot for use as media blanks.

d. **Sampling Instructions for Filter + Cyclone Sampler**

Use these instructions for personal sampling of respirable aerosols (ACGIH definition [20]). Methods requiring these instructions specify CYCLONE + FILTER as the sampling method.

(1) Calibrate the pump to the rate specified by the cyclone (1.7 L/min for the 10-mm nylon cyclone, 2.2 L/min for the Higgins-Dewell cyclone [21], or 2.5 L/min for the aluminum cyclone), with a representative cyclone sampler in line using a bubble meter or a secondary flow measuring device which has been calibrated against a bubble meter. The calibration of the personal sampling pump should be done close to the same altitude where the sample will be taken.

(2) Assemble the pre-weighed filter in the two-piece cassette filter holder. Support the filter with a cellulose backup pad or stainless steel screen. Close firmly to prevent sample leakage around the filter. Seal the filter holder with plastic tape or a shrinkable cellulose band.

(3) Remove the cyclone's grit cap and vortex finder before use and inspect the cyclone interior. If the inside is visibly scored, discard this cyclone since the dust separation characteristics of the cyclone might be altered. Clean the interior of the cyclone to prevent reentrainment of large particles.

(4) Assemble the two-piece filter holder, coupler, cyclone and sampling head. The sampling head rigidly holds together the cyclone and filter holder. Check and adjust the alignment of the filter holder and cyclone in the sampling head to prevent leakage. Connect the outlet of the sampling head to the personal sampling pump by a 1-m piece of 6-mm ID flexible tubing.

(5) Clip the cyclone assembly to the worker's lapel and the personal sampling pump to the belt. Ensure that the cyclone hangs vertically. Explain to the worker why the cyclone must not be inverted.

(6) Prepare the field blanks at about the same time as sampling is begun. These field blanks should consist of unused filters and filter holders from the same lot used for sample collection. Handle and ship the field blanks exactly as the samples, but do not draw air through the field blanks. Two field blanks are required for each 10 samples with a maximum of 10 field blanks per sample set.

(7) Turn on the pump and begin sample collection. If necessary, reset the flow rate to the pre-calibrated value, using the manufacturer's adjustment procedures. Since it is possible for a filter to become plugged by heavy particulate loading or by the presence of oil mists or other liquids in the air, observe the filter and personal sampling pump frequently to keep the flow rate within ± 5% of the target flow rate. The sampling should be terminated at the first evidence of a problem.

(8) Disconnect the filter after sampling. Cap the inlet and outlet of the filter holder with plugs. Label the sample. Record pertinent sampling data including times of beginning and end of sampling, initial and final air temperatures and atmospheric pressure or elevation above sea level. Record the type of personal sampling pump, filter, cyclone used and the location of the sampler.

(9) Ship the samples and field blanks to the laboratory in a suitable container designed to prevent damage in transit. Ship bulk samples in a separate package.

(10) Take two to four replicate samples for every set of field samples to assure quality of the sampling procedures. The set of replicate samples should be exposed to the same dust environment, either in a laboratory dust chamber or in the field. The quality control samples must be taken with the same equipment, procedures and personnel used in the routine field samples. The relative standard deviation, s_r, calculated from these replicates should be recorded on control charts and action taken when the precision is out of control.

e. **Jarless Method of Calibration of Cyclone Assemblies [23]**

This procedure may be used in the field to calibrate an air sampling pump and a cyclone assembly without using the one-liter "calibration jar."

(1) Connect the pump to a pressure gauge or water manometer, a light load equal to 2 to 5" H_2O, and an electronic bubble meter or standard bubble tube.

(2) Adjust the pump to 1.7 L/min as indicated on the bubble meter/tube, under the light load conditions (2 to 5" H_2O) as indicated on the pressure gauge or manometer.

(3) Increase the load until the pressure gauge or water manometer indicates between 25 and 35" H_2O. Check the flow rate of the pump again. The flow rate should remain at 1.7 L/min ± 5%.

(4) Replace the pressure gauge or water manometer and the electronic bubble meter or standard bubble tube with the cyclone having a clean filter installed. If the loading caused by the cyclone assembly is between 2 and 5" H_2O, the calibration is complete and the pump and cyclone are ready for sampling.

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Chapter 17

Direct-Reading Instruments for Gases, Vapors, and Particulates

by Rolf M.A. Hahne, PhD, CIH

The concentration of many gases, vapors, and particulates in air can be measured readily by direct-reading instruments or other direct-reading devices, which perform both sampling and measurement. The user can read the concentration through a digital or analog readout or, for some colorimetric devices, by observing the length or intensity of a color stain.

A direct-reading instrument should be capable of sampling air in the breathing zone of the worker or in the work area of concern and should indicate the concentration of the substance (or class of substances, in the case of nonspecific instruments), either as an instantaneous concentration or as a time-weighted average, depending on the capabilities of the device.

This chapter is structured to first discuss direct-reading instruments that are intended for the measurement of a single compound or group of compounds, such as combustible gases. The second part of the chapter addresses direct-reading instruments that have wide applicability for the detection of many different compounds or substances, such as particulates.

MONITORS INTENDED FOR ONE COMPOUND OR GROUP OF COMPOUNDS

Combustible Gas Monitors

Many portable direct-reading instruments for the measurement of combustible gases and vapors are commercially available. The operator must be thoroughly familiar with the calibration, use, and limitations of the instrument being used because an elevated level of combustible gases in the environment could be life-threatening. These instruments are based on one of two principles: the change in resistance of a conductor subjected to heat released by gas combustion, or the change in electrical conductivity of a metallic oxide semiconductor in the presence of a combustible gas. Both types require calibration using a reference gas (often pentane or hexane) and must be interpreted correctly.

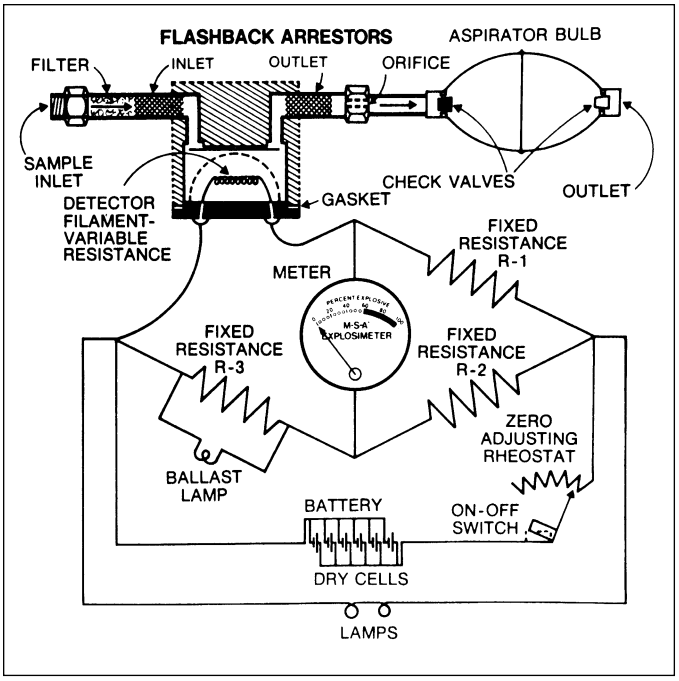

Figure 17–1. A schematic diagram of a typical hot-wire combustible gas monitor. (Courtesy MSA.)

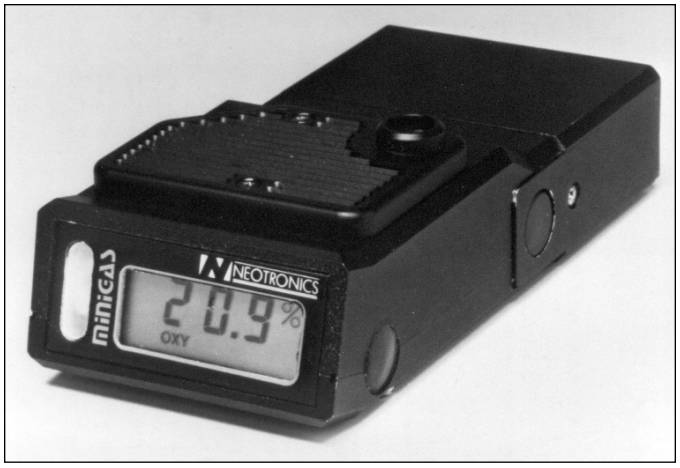

Figure 17–2. A multigas monitor that uses catalytic decomposition to measure combustible gases. (Courtesy Neotronics of North America, Inc.)

EXPLOSIVE (FLAMMABLE) LIMITS (LEL/UEL)

When certain proportions of combustible vapor are mixed with air and a source of ignition is present, a fire or explosion can occur. The range of concentrations over which this occurs is called the explosive (or flammable) range. The low end of this range is called the lower explosive (or flammable) limit (LEL), and the high end is called the upper explosive (or flammable) limit (UEL). The explosive (flammable) range and the lower and upper explosive limits are expressed as volume percents. If the atmosphere is above the UEL, dilution with fresh air could bring the mixture into the flammable or explosive range, so any atmosphere with a flammable or explosive gas near or above the UEL should be considered a significant explosion hazard.

On the simplest type of combustible gas instrument, only one sensitivity is provided, usually with readings from 0 to 100 percent of the LEL. Different models of combustible gas meters are supplied with meters that range from 5 percent of the LEL to 100 percent by volume of the combustible gas, full scale.

INSTRUMENT DESIGN

Combustible gas monitors are based on three different types of detectors. They are the catalytic combustible gas sensor, the metal oxide semiconductor (MOS) detector, and the thermal conductivity detector. They are described below in more detail. Monitors using each of these types of combustible gas detectors are commercially available, and many are multi-gas monitors containing additional sensors that allow for the measurement of percent oxygen and parts per million (ppm) levels of toxic gases such carbon monoxide or hydrogen sulfide.

In the catalytic combustible gas detector, heat is released when a combustible gas or vapor, in contact with the detector, is burned (oxidized). In simple versions of these monitors, the detector element is a heated coil of platinum wire that forms one arm of a Wheatstone bridge circuit (see Figure 17–1). The heat released by the burning causes a change in the electrical resistance of the detector filament that is proportional to the combustible gas concentration. The change in resistance produces an imbalance in the bridge circuit that can be measured electrically and is translated into a combustible gas concentration.

More recent versions of the sensors for catalytic combustion devices have a matched-pair of alumina coated filaments. The sensing filament forms one leg of a Wheatstone bridge and burns the combustible gas. The compensating filament forms a second leg of the Wheatstone bridge but does not burn the combustible gas. In all other respects the two filaments behave similarly. This improved catalytic combustible gas sensor allows for significantly improved zero and span stability. It also corrects for thermal conductivity effects (see below) related to non-combustible atmospheric impurities. A combustible gas monitor that uses this type of sensor is shown in Figure 17–2.

In the MOS gas sensor (Figure 17–3), a change in the electrical conductivity occurs when a combustible gas is adsorbed on the surface of a semiconductor. This change in electrical conductivity is proportional to the concentration of the combustible gas present and is translated into a combustible gas concentration. Changing the surface temperature of the sensor by varying the power delivered to its heater alters the sensitivity of the MOS sensor to a given compound. In principle, this allows the MOS sensor to show some compound selectivity.

In the third type of instrument (Figure 17–4), the atmosphere to be measured for combustible gas concentration

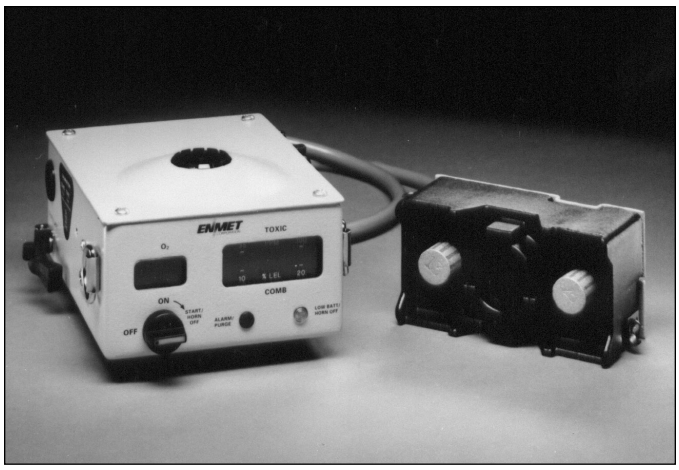

Figure 17–3. A multigas monitor that uses a metal oxide semiconductor detector to measure combustible gases. A detachable sensor head for remote sampling is one feature of this instrument. (Courtesy ENMET Corporation.)

Figure 17–4. A multigas detector that can use a thermal conductivity probe for high concentrations of combustible gases (0-99.9 percent by volume). (Courtesy GfG Gas Electronics, Inc., 200 S. Hanley, St. Louis, MO 63105.)

passes over a heated filament that is sensitive to the thermal conductivity changes in air created by the presence of combustible gases. The sensor generally gets hotter (with lower thermal conductivity) in proportion to the combustible gas concentration and its electrical resistance changes. A Wheatstone bridge circuit converts the resulting sensor resistance change to a voltage that is proportional to the combustible gas concentration.

Rather than having only a percent LEL range, the combustible gas monitor shown in Figure 17–5 has been optimized to measure methane in the ppm, percent LEL, and percent gas ranges. To produce the large signal necessary to achieve ppm level sensitivity, and improve the response time, gas is pumped through the instrument probe. In the ppm and percent LEL range, both the sensing and compensating filaments are used. Above the LEL range, the sensing filament is turned off and the compensating element is used as a thermal conductivity detector. This type of instrument has found widespread use in the utility industry to identify natural gas leaks while protecting worker safety.

Because the heat of combustion, the adsorptive properties of a combustible gas on the surface of an MOS, and thermal conductivity are all compound-dependent, instrument response for all these instruments is compound-dependent. Similarly, the lower explosive limits of combustible gases are also compound-dependent. Thus, a combustible gas meter is typically calibrated with a particular compound (often pentane or hexane) such that the concentration of other combustible gases present would be overestimated by an instrument calibrated with methane. Instrument manufacturers often provide calibration curves or tables for a variety of different combustibles, for use in correlating meter readings to the concentration of nonmethane gases and vapors. Figure 17–6 is an example of such a table.

All combustible gas meters that rely on a heated wire or filament—an ignition source—have a flashback arrestor that prevents the combustion in the detector from spreading to the atmosphere outside the instrument. This means that they are intrinsically safe (that is, they can be operated safely in flammable or explosive atmospheres). The manufacturer's instructions for operating a combustible gas meter should be carefully reviewed before the device is used. In general, combustible gas meters require a brief initial warmup period so that the batteries can heat any components that operate at an elevated temperature.

Air is drawn through the sampling probe and into the detector by means of a small sampling pump or a hand-operated squeeze bulb. In some cases, air diffuses into the instrument without being actively drawn in. In most work areas, the concentration of combustible gas or vapor fluctuates constantly and it is necessary to observe the instrument carefully to determine average and peak readings. Some instruments have built-in data-logging features that can store and recall integrated average and peak measurements.

Figure 17–5a. A Gasport® combustible gas monitor. (Courtesy MSA.)

Figure 17–5b.

Figure 17–5c.

Figure 17–5d.

ZERO ADJUSTMENT

The zero adjustment must be made by taking the instrument to a location that does not contain combustible gases or by passing air into it through an activated carbon filter that removes all combustible vapors and gases (except methane). Because methane is not removed by activated charcoal filters, extra caution is required during zeroing if the presence of methane is suspected. In addition, the charcoal filter should be changed periodically because it becomes inactivated by moisture or hydrocarbon saturation.

INTERPRETATION OF METER READINGS

The user of any instrument should be thoroughly familiar with the necessary precautions. Users of combustible gas meters must be aware of interfering gases and vapors that could create discrepancies in instrument response. All

GAS BEING SAMPLED	CALIBRATION GAS: Acetone	Butane	Hexane	Hydrogen	Methane	Propane
Benzene	1.1	1.1	0.7	1.9	1.9	1.2
Methane	0.6	0.6	0.4	1.0	1.0	0.6
Methanol	0.6	0.6	0.5	1.1	1.1	0.7
Ethylene	0.8	0.8	0.6	1.4	1.3	0.9
Toluene	1.3	1.2	0.9	2.1	2.1	1.3
Acetone	1.0	1.0	0.7	1.7	1.7	1.1

Example: The instrument has been calibrated on methane and is now reading 10% LEL in a toluene atmosphere. To find the actual percent LEL, multiply by the number found at the intersection of the methane column (calibration gas) and the toluene row (gas being sampled)—in this case, 2.1. Therefore, the actual percent LEL is 21% (10% x 2.1).

Multiplier accuracy is ±25%, subject to change without notice, pending additional testing.

If the sensor is used in atmospheres containing unknown contaminants (silicone, sulfur, lead, or halogen compound vapors) methane is the recommended calibration gas. Periodic comparison of methane and pentane readings is recommended when using this chart. Contact Industrial Scientific for details.

Figure 17–6. A table of correction factors for the catalytic combustion sensor, based on the gas used for calibration. (Based on a table courtesy of Industrial Scientific Corp.)

instruments are subject, to some extent, to interferences from noncombustible and nonexplosive gases. For example, the presence of argon, which has a lower thermal conductivity than air, could create a false positive reading in combustion and thermal conductivity detectors. As a precaution, the least-sensitive LEL scale (generally 0–100 percent of the LEL) should be used first to determine whether an explosive atmosphere exists and to prevent overloading of a more sensitive (0–10 percent of LEL) scale. The typical meter responses to methane gas are shown in Figure 17–7 at the LEL, in the explosive range, and above the UEL.

If the indicator of the meter moves above the UEL and remains there, an explosive concentration of gas or vapor is present. However, if the meter climbs rapidly and then falls back to zero, there is either a concentration above the UEL or a gas mixture that lacks sufficient oxygen to support combustion. The instrument may read zero for several different reasons. Assuming that the instrument is functioning properly, the absence of an instrument response can mean either that there is little or no combustible gas in the space being tested or that the concentration is significantly above the UEL and combustion cannot occur because of insufficient oxygen.

Great care must be exercised to ensure that a reading above the UEL is not misinterpreted as a true zero reading. Figure 17–8 is a reminder of the importance of proper interpretation of the instrument readings, in this case in evaluation of the atmosphere in a confined space. A very high concentration of combustible gas can be identified by carefully watching the

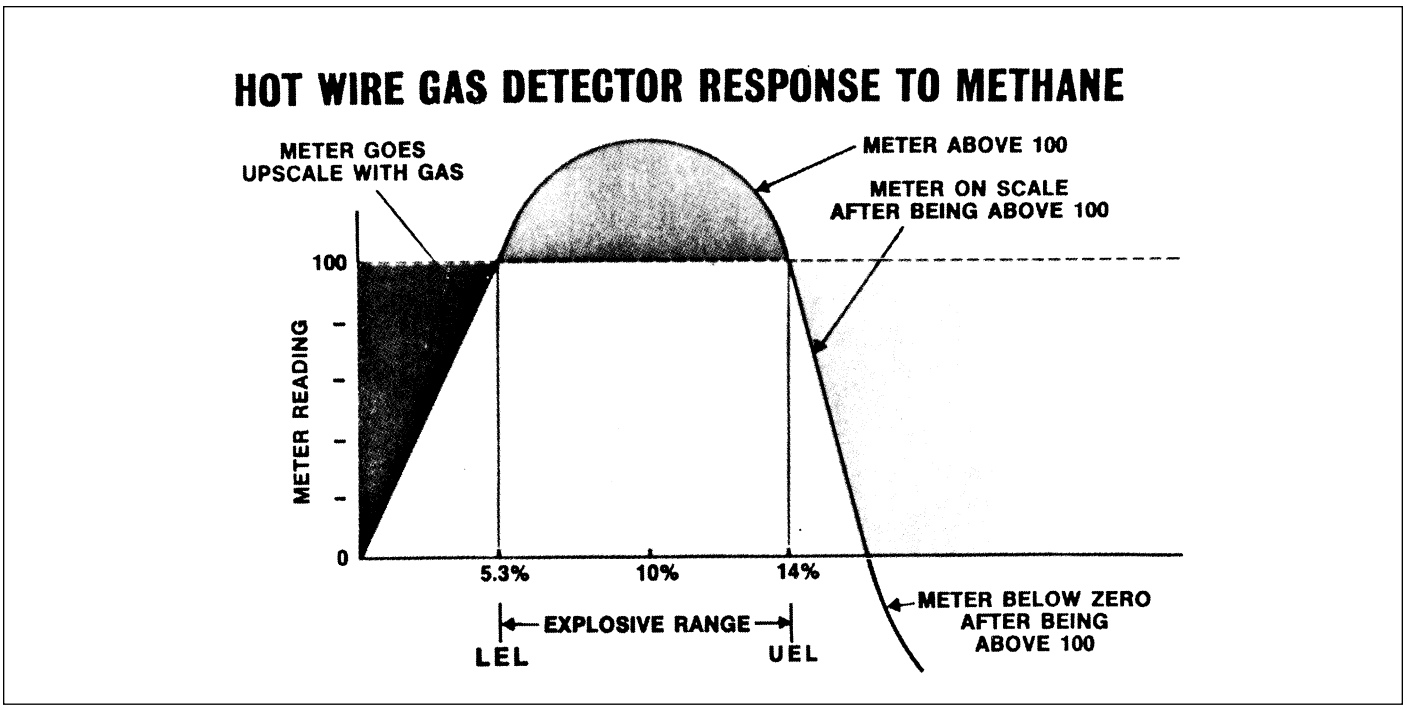

Figure 17–7. The relationship between meter reading and combustible gas concentration. (Courtesy MSA.)

needle as the probe is moved into and withdrawn from the space being tested. At some point during entry and withdrawal, the instrument will exceed the LEL if a level above the LEL is actually present. These instruments should not be used to measure the concentration of combustible gases in steam or inert atmospheres because of the measurement uncertainties or interferences in nonair atmospheres.

HIGH-FLASH-POINT SOLVENTS

Although it is relatively easy to operate a combustible gas indicator to detect a flammable gas or vapor, these instruments have some limitations. They respond only to combustible vapors drawn into the detector cell. If the vapor pressure of a combustible liquid is relatively low at room temperature, a relatively low concentration will be indicated. If a closed vessel holding a liquid contaminant is later heated (by welding or cutting, for example) the vapor concentrations will increase and the concentration of the substance in the atmosphere of the container, which originally was quite low, may increase and become explosive. Continuous monitoring may be recommended in this situation. When testing the atmosphere in drying ovens or other places where the temperature is unusually high, there may be some difficulty in measuring solvents (such as naphthas) that have a relatively high boiling point because the vapors may condense in the sampling line, thus giving a false indication of safety. In some instances, condensation can be prevented by heating the sampling line and the instrument to a temperature equal to or above that of the space to be tested.

Several types of combustible gas monitors have been designed to be calibrated so that specific combustibles can be measured. One variation of the instrument has adjustable calibration controls and can measure five different gases or vapors in the 0–100 percent LEL range for each. Another type has a dual-scale multiple-calibration curve in the 0–10 percent and 0–100 percent range of the LEL.

CATALYST POISONING

Because minute concentrations of silicone vapors—even 1 or 2 ppm—can rapidly poison the catalytic activity of the platinum filament, a hot-wire combustible gas indicator should not be used in areas where silicone vapors are present.

INTERFERENCES

Interfering gases and vapors can seriously affect instrument response; an experienced tester recognizes the indications of their presence. Instrument manufacturers' instructions should be followed carefully because high concentrations of chlorinated hydrocarbons (such as trichloroethylene) or acid gases (such as sulfur dioxide) may cause depressed meter readings in combustion-type meters where high concentrations of combustibles are present. Trace amounts of these interferences may not affect the readings directly but can corrode the detector elements. High-molecular-weight alcohols in the atmosphere may burn out the filaments, rendering the instrument inoperative. When such limitations are understood, the tester can obtain reliable and accurate results.

OTHER FEATURES

Combustible gas monitors are available with audible and visual alarms. When the concentration reaches the preset limit, an alarm light and a loud alarm are activated, providing

Figure 17–8. A worker cautiously monitors a confined space in order to evaluate its atmosphere. (Courtesy Draeger Safety, Inc.)

visible and audible warnings of a dangerous concentration. Figure 17–9 shows an instrument with a dual alarm. The audible alarm can be switched off; in this case, the pilot light will blink until the unit is reset and the combustible gas concentration falls below the set point. The manufacturer's instructions should be consulted for further details on the operation of such alarms.

Oxygen Monitors

Although oxygen does not have a specific occupational exposure level, its level in workplace air must often be measured, particularly in enclosed areas where combustion or other processes may use up the available oxygen. Excess oxygen from oxyacetylene or oxyhydrogen flame operation should also be monitored to prevent a fire hazard. Air normally contains about 21 percent oxygen by volume. Sixteen percent oxygen is considered the minimum to support life. In some cases, however, air with less than 19.5 percent oxygen may be considered deficient, such as at high altitudes where atmospheric pressures are lower.

In many locations, such as mines, manholes, tunnels, or other confined spaces, the oxygen content can become low enough to be life-threatening. In such situations, it is necessary to determine the oxygen content of the air. In addition, it is necessary to take a sample to determine whether combustible gases are present in dangerous concentrations. Direct-reading oxygen monitors are small, lightweight, and easy to use. The instruments generally use a coulometric cell to detect oxygen. A few instruments that rely on the paramagnetic property of molecular oxygen are also available commercially.

COULOMETRIC DETECTORS

Coulometric detectors rely on the measurement of current flowing in an electrolyte between two electrodes, maintained at a controlled voltage difference, as a result of an oxidation-reduction reaction in the detector cell. The current flow is translated into an airborne concentration of the contaminant undergoing the oxidation or reduction. The most commonly used detector cell for oxygen is a coulometric cell, which has a semipermeable membrane that selectively allows oxygen to enter the cell. One of the electrodes is consumed during the flow of electrons, thus limiting the lifetime of the cell. The cells are temperature-compensated through the use of an external thermistor. Cells from different manufacturers have

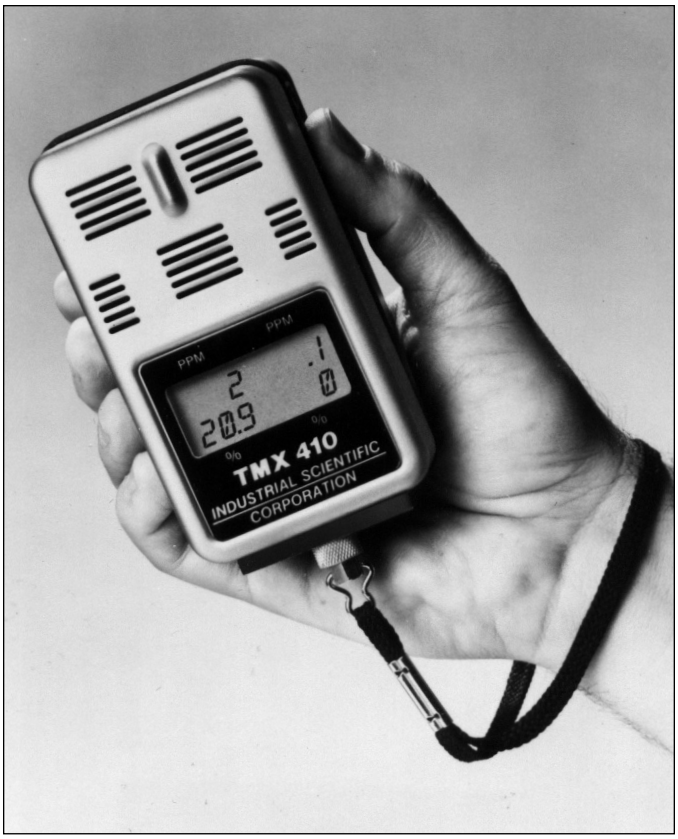

Figure 17–9. A multigas monitor that has an adjustable set point and audible and visible alarms. (Courtesy Industrial Scientific Corp., Oakdale, Pa.)

Figure 17–10. A direct-reading carbon monoxide monitor capable of data storage and readout. (Courtesy Draeger Safety, Inc.)

different response times, accuracies, and temperature and relative humidity performance ranges.

POLAROGRAPHIC DETECTORS

Polarographic detectors rely on two parameters: the ability of the compound of interest to be chemically oxidized or reduced at an electrode at a given electrode potential, and the rate-determining step of the discharge of ions at a microelectrode that is determined by diffusion. Polarographic detectors are used to measure oxygen and carbon monoxide in ambient air.

Carbon Monoxide Monitors

One of the most insidious toxic gas hazards in an industrial atmosphere is carbon monoxide. Odorless, tasteless, and colorless, carbon monoxide can be deadly even in small concentrations. Carbon monoxide can occur in many areas, including gas and utility properties, garages, bus terminals, sewers, vaults, blast furnaces, open-hearth furnaces, and mines. A number of instruments are available for measuring carbon monoxide (Figure 17–10).

The most common instruments use a potentiometric or coulometric cell. The resulting voltage or current is translated into a concentration, with temperature compensation factored in. Samples are introduced to the detector cell through a diffusion barrier. Potentiometer cells rely on a change in voltage difference between two electrodes in the presence of a particular air contaminant. Typical portable carbon monoxide detectors feature both visible and audible alarms that alert the user when the danger level is reached. Battery-powered instruments can measure carbon monoxide in the atmosphere in the range of 1–2,000 ppm by volume.

Indoor Air Quality Monitors

Industrial hygienists increasingly need to assess building air quality and require direct-reading recording instruments for measuring key parameters of indoor air quality. Commercially available devices measure temperature, relative humidity, carbon dioxide, and often several other parameters (chosen by the purchaser) simultaneously, as indicators of the quality of the indoor environment (Figure 17–11).

The carbon dioxide monitor and other toxic gas monitors used in these devices are often of the types described in this section. The discussion of temperature and relative humidity measurement is beyond the scope of this chapter, but both parameters can be measured with precision with probes that

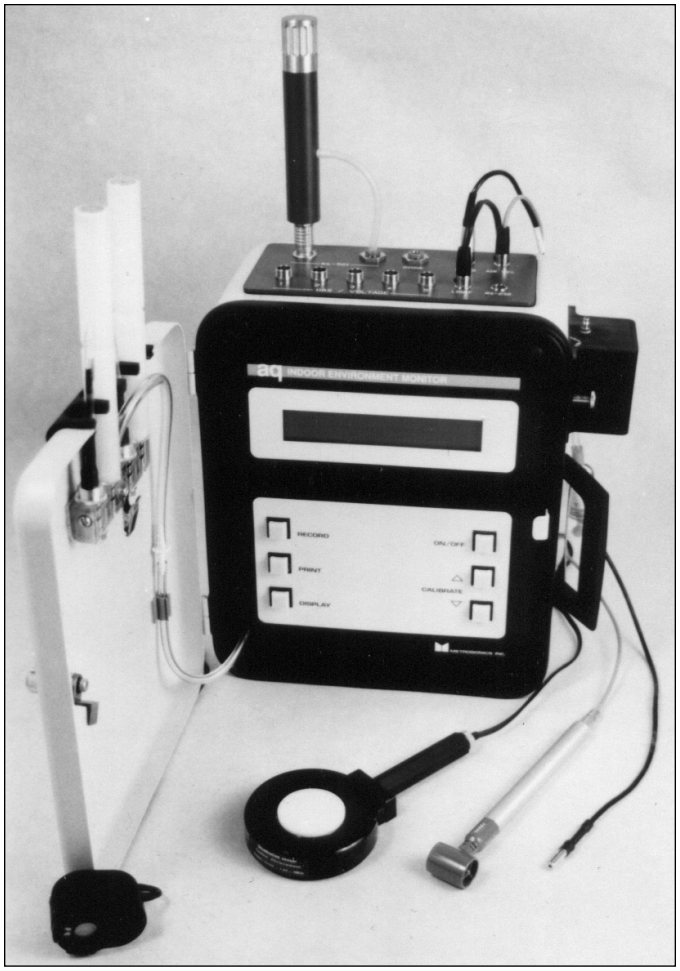

Figure 17–11. An indoor environmental monitor for measuring temperature, relative humidity, carbon dioxide, and one other parameter. (Courtesy Metrosonics, Inc.)

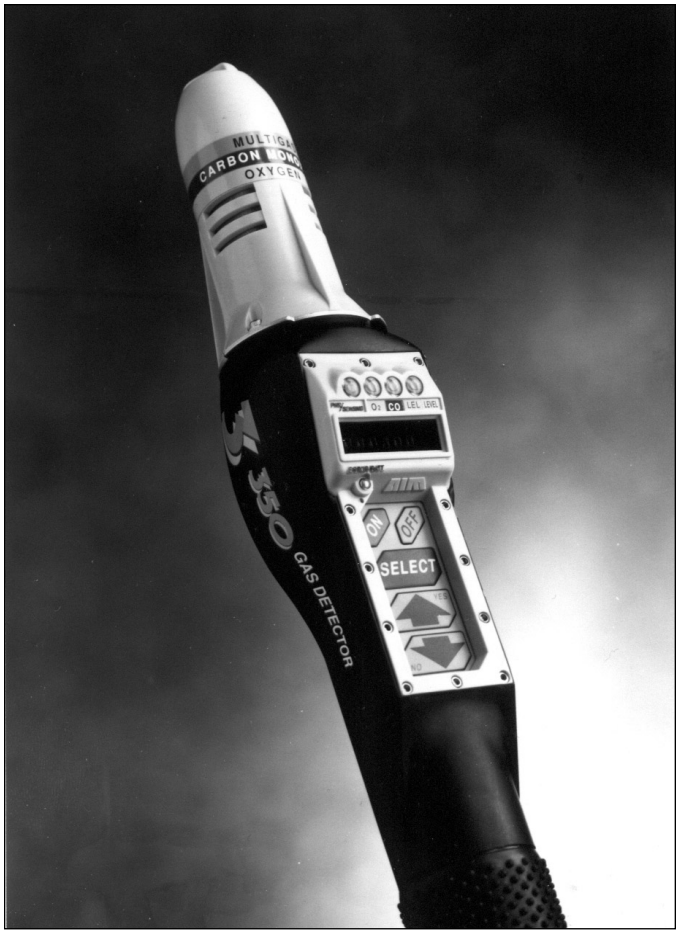

Figure 17–12. A multigas monitor using a metal oxide semiconductor sensor for combustible gases and electrochemical sensors for oxygen and toxic gases. (Courtesy AIM Safety USA, Inc.)

are readily available. (For more information, see Chapter 21, General Ventilation of Nonindustrial Occupancies.)

Other Monitors Using Electrochemical or Metal Oxide Semiconductor Detectors

A number of instruments, usually containing multiple sensors, are available for detection of a large number of different compounds (Figures 17–2, 17–3, 17–4, 17–9, and 17–12).

These instruments are typically based on electrochemical cells, either potentiometric (galvanic) or coulometric, described in the section on oxygen and carbon monoxide monitoring. They almost always have combustible gas and oxygen deficiency sensors, in addition to other toxic gas sensors. Sensors are commercially available for H_2S, SO_2, Cl_2, NO, NO_2, H_2, HCN, HCl, and NH_3.

All of these sensors are affected by other compounds, which interfere with the measurement of the compound of interest. However, sensor specificity for these compounds can be enhanced by adding filters that remove potential interferences, controlling the voltage in a coulometric cell to minimize unwanted oxidation-reduction reactions, choosing an appropriate sensing electrode that catalyzes only the oxidation or reduction of the chemical species of interest, or introducing a semipermeable barrier into the cell to minimize the entry of interfering gases. For example, one manufacturer of H_2S sensors provides a list of cross-sensitivities for its device, listing 11 compounds and 2 classes of compounds (saturated and unsaturated hydrocarbons) that may interfere. Among these, only HCN, HCl, Cl_2, and $COCl_2$ give positive interferences; NO_2 gives a negative interference. The sensitivity of the sensor to HCN is half that for H_2S, and for the others 0.2 times or less that for H_2S.

At present, multiple-gas monitors are available that can accommodate up to five different detectors at a time. These instruments are typically configured to include combustible gases and vapors, oxygen, and carbon monoxide, all of which are of interest in confined spaces, but could include any compound. Two manufacturers currently manufacture detector cells for 11 different compounds or combustible gases and vapors. (See Carner et al, 1994.)

Mercury Vapor Monitors

Portable, battery-operated ultraviolet analyzers are available for mercury vapor. The section on ultraviolet spectrophotometers has more information on the principles of operation of such devices. In this instrument, the wavelengths of ultraviolet light emitted from a mercury vapor lamp are absorbed by mercury vapor in the ambient air drawn into the instrument. In a dual-beam instrument, the ratio of the intensity of this absorption to that in a reference cell is translated electronically into a concentration of mercury vapor in the air. The specificity of absorption enables the instrument to detect well below 0.05 mg/m^3.

Another type of mercury-specific direct-reading instrument (Figure 17–13) relies on the change in electrical con-

Figure 17–13. An instrument for monitoring mercury vapor based on the conductivity of a gold foil. (Courtesy Arizona Instrument Corporation.)

ductivity of a gold foil when it comes into contact with mercury vapor to form an amalgam (a solid solution of another metal in mercury). Air containing mercury vapor is drawn into the cell and amalgamates the gold. The conductivity of the amalgam is different from that of the pure gold and the change in conductivity is related to the concentration of mercury in the air sampled during the fixed sampling periods of 1 or 10 seconds. Periodically, after the conductivity changes are significant, the gold foil is heated by an external power source and the amalgam is destroyed as the mercury vapor is driven off by the high temperature. The foil, thus renewed, is ready for a new series of measurements. An instrument based on the same measurement principle—the change in electrical resistance when a gold foil reacts with the gas of interest—is available for direct measurement of hydrogen sulfide (H_2S) as well.

Formaldehyde Vapor Monitor

Although there have been a number of instruments developed over the past 20 years that were specific for formaldehyde, few of them can measure concentrations at the current TLV® ceiling level of 0.3 ppm (v/v). One instrument that claims to measure down to 0.01 ppm of formaldehyde over a five-minute sampling period is based on the principle of fluorescence. In a fluorescence method, the intensity of electromagnetic radiation emitted from the molecules of interest after they have been excited with monochromatic light is measured. This intensity is related to the concentration of the molecules present and allows essentially real-time measurements to be done.

Direct-Reading Colorimetric Tubes and Badges

Direct-reading colorimetric devices use the reaction of an airborne contaminant with a color-producing agent to yield a stain length or color intensity, which can be directly read to provide an instantaneous or time-weighted average value of the concentration of that contaminant. The colorimetric detector tube and badge are widely used by industrial hygienists and other health professionals. Their simplicity of operation, low initial cost, and the availability of multiple types for the detection of numerous contaminants make these popular devices for field use. Nevertheless, like nearly all direct-reading instruments, these devices are limited in applicability, specificity, and accuracy. The user must be familiar with these critical limitations if proper judgments are to be made about appropriate use and about the results.

DETECTOR TUBES

Colorimetric detector tubes provide a simple and economical method of measuring the exposure of workers to toxic vapors. The tubes are generally not specific for a single compound because nearly all have interferences. In atmospheres that are well-characterized for such interferences, they can be useful for estimating concentrations of certain airborne contaminants. The cost of chemical indicator tubes is considerably less than the cost of a chemical analysis of a sorbent tube in the laboratory. However, the sensitivity of the tubes, their lower accuracy, the possible presence of interferences, and the potential lack of appropriate tubes for determining anything more than instantaneous concentrations are all limitations that must be considered when using these devices.

Figure 17–14. Length-of-stain tubes intended for short sampling periods. (Courtesy Draeger Safety, Inc.)

PRINCIPLES OF OPERATION

The hermetically sealed glass tubes contain an inert granular material impregnated with an agent that develops a color when it reacts with the contaminant (Figure 17–14).

Sometimes there is a section in the tube or a separate tube that first causes a reaction to take place before the indicating section. For certain inert compounds, a pyrolyzer that thermally decomposes the compound into a form detectable by an indicator tube is available as an attachment to the hand pump. Chemical indicator tubes can be characterized by how the air reaches the active portion of the tube: by active sampling using a hand pump (for short-term measurements) or battery-operated pump (for longer-term measurements) or by passive sampling relying on diffusion. Tubes can be categorized as short-term measurement tubes or longer-term time-weighted average measurement tubes.

Some brands of detector tubes are calibrated in milligrams per cubic meter. Conversion from milligrams per cubic meter to parts per million at 77 F (25 C) and 760 mmHg (standard temperature and pressure) can be performed using the following equation:

$$\text{ppm} = \frac{\text{Milligrams per cubic meter} \times 24.45}{\text{Molecular weight (grams per mole)}} \quad (1)$$

ACTIVE SAMPLING

In a test using an actively sampled tube, both ends of the indicator tube are broken off and a volume of air is drawn through the tube, using a hand pump or electrically operated pump (Figure 17–15).

Most such tubes have an increased sensitivity if larger volumes of air are drawn through the tube. For tubes intended for multiple compound detection, a linear scale may be printed on the tube and the relationship of that scale to contaminant concentration is provided separately. The manufacturer prints a calibration curve on the tube and also provides instructions for interpretation of the stain length when multiples of the minimum volume of air (typically 50 or 100 mL) are drawn through the tube. Tubes used with hand pumps are usually designed to determine average concentrations of an airborne contaminant over periods of 0.5–10 min, depending on the total air volume drawn through the tube. See the American Society for Testing and Materials (ASTM) "Standard Practice for Measuring the Concentration of Toxic Gases or Vapors Using Length-of-Stain Dosimeters" (ASTM D 4599–86) for further information.

Tubes designed for use with a battery-operated pump have been developed for determination of longer-term (1–8 h) time-weighted average concentrations. The color development principle on which they are based is often identical to that for short-term tubes. However, the readings on the tube are often given as ppm-hours and the time-weighted average concentration of the contaminant is determined by dividing the reading by the sampling time (in hours). A relatively new development in the field of colorimetric tubes is a device that does the actual reading of the stain length and displays the results digitally. This device has in it 10 capillary tubes mounted on a chip, each tube filled with a reagent that develops a color when in contact with the contaminant of interest. A pump draws a known quantity of air through a single capillary, and the optics of the instrument read the length of the stain formed in the capillary. Ten measurements can be made before the chip must be replaced. At this writing, chips are available for 12 different compounds or groups of compounds, three at more than one level.

FLOW RATE

Flow rates for length-of-stain devices must be maintained in accordance with the manufacturer's operating instructions and the flow rates of the pumps used with length-of-stain devices must be checked periodically. Proper flow rate ensures an appropriate residence time of the air sample in the device and provides sufficient time for the contaminant to react with the chemicals in the detector tube. To obtain meaningful test results, the residence time must be the same as that used to develop the color chart or length-of-stain chart supplied by the manufacturer.

Figure 17–15. Manual and automatic pumps for short sampling period tubes. (Courtesy Draeger Safety, Inc.)

Although one would be hard-pressed to call such devices instruments, there are commercially available, direct-reading indicators that are worn underneath chemically resistant gloves to give an indication of when breakthrough of any of a group of compounds has taken place. The indicator contains a microencapsulated (proprietary) detection indicator that changes color when in contact with a significant quantity of the compound of interest. Current indicators are available for the following groups of compounds: aromatic amines, aliphatic amines, aromatic isocyanates, aliphatic isocyanates, acids/bases, hydrazines, polynuclear aromatic hydrocarbons, solvents (including ketones, glycol ethers, and chlorinated hydrocarbons), and heavy metals.

PASSIVE MONITORS

Sampling for contaminants using some colorimetric tubes can also be performed without using a pump to draw air into detector tube. These tubes are called passive or diffusional

monitors. The driving force moving air into the tube is the difference in contaminant concentration between the ambient air and inside the tube at the point of reaction (where it is effectively zero). Some passive sampling tubes can be used to sample the atmosphere for several hours, whereas others are intended for only short sampling periods. Passive colorimetric monitors generally are calibrated in ppm-hours. The time-weighted average concentration during the period the tube is exposed to the air equals the ppm-hours indicated on the tube divided by the number of hours the tube was open. Although most passive tubes function on the same chemical principle as actively pumped tubes, a few passive tubes are calibrated from the closed end of the tube: The air contaminant diffuses into the closed end of the tube and then creates the stain as it re-diffuses back toward the open end, chemically modified.

One manufacturer of passively sampling chemical indicator tubes has shown that wind velocities below 0.011–0.022 mph (0.5–1.0 cm/s) result in undersampling of the contaminant, giving a lower reading than the true value. Therefore, these devices should not be used as area samplers where there is little or no air movement. Conversely, they recommend that the devices not be used in situations in which the air velocity past the tube opening exceeds 5.6 mph (250 cm/s), lest the contaminant be oversampled, giving a concentration higher than the true value.

INTERPRETING THE RESULTS

It is important to recognize that some color stains fade or change with time. Thus, readings of stain length should be made as promptly as possible or in accordance with the manufacturer's recommendations. The ability to read color-change detector tubes and badges depends on the color perception of the observer and the lighting conditions. The exposed devices should be examined in an area with daylight or incandescent illumination rather than fluorescent lighting. Mercury vapor lamps should generally be avoided because the color change may not be visible and the end of the color stain may be difficult to perceive.

With most length-of-stain tubes, the stain front may not be sharp, so the exact length of stain cannot be readily determined. It could be helpful to obtain the results of a calibration test performed on known concentrations before using the tubes in the field. The National Institute for Occupational Safety and Health (NIOSH) has specified that such tubes must yield a concentration value within ±25 percent of the true value, as determined by a reference method, at the occupational exposure limit.

Obviously, performing reliable tests with indicating tubes requires careful use and thorough knowledge of their limitations. Experience has shown that the following measures help to minimize some errors:

- ➢ Test each batch of tubes with a known concentration of the air contaminant to be measured.
- ➢ Read the length of stain in a well-lighted area.
- ➢ Comply with the manufacturer's expiration date and discard outdated tubes.
- ➢ Store detector tubes in accordance with the manufacturer's recommendations.
- ➢ Refer to the manufacturer's data for a list of interfering materials.

SPECIFICITY

Most colorimetric detector tubes, both passive and active, are intended to measure a specific compound (or group of compounds) such as hydrogen sulfide, chlorine, mercury vapor, alcohols, or hydrocarbons. Because no device is completely specific for the substances of interest, care must be taken to ensure that interferences do not invalidate the sampling results. Specificity is one of the primary considerations in selecting a detector system. In most cases, the manufacturer has identified interfering substances and conditions and has included this information in the instructions enclosed with the tubes. Sometimes a preconditioning section is used in the detector tubes to remove potential contaminants, convert the gas or vapor of interest to a more suitable reacting compound, and react with the gas or vapor with the release of a new gas or vapor that can be measured by the second section.

Chemical reactions that occur in the detector tubes are temperature-dependent. The tube's instructions give an acceptable temperature range in which it is usable. Drastic differences in the temperature affect the volume of air going through the detector tube, but the uncertainty produced by the effect of temperature on volume is modest compared with other uncertainties in the measurement. Interchanging tubes obtained from various manufacturers will lead to erroneous results because the sampling rates of the various pumps are not the same, nor are the reaction rates of the chemical reagents in the indicator tubes. Each manufacturer produces, calibrates, and sells equipment as an integral system; tubes produced by one manufacturer and pumps produced by another should not be mixed.

SHELF LIFE

The shelf life of detector tubes is a critical consideration because the tubes may not be used very often and, therefore, may not be used within the manufacturer's expiration date. Often, tube life can be extended by storage under refrigeration, but tubes should not be used beyond the expiration date unless the response of the expired tubes is compared with that of tubes that have not yet expired or tested with a calibration gas. Freezing temperatures should not adversely affect a tube's shelf life; however, the tubes must be warmed to room temperature before use. Detector tubes should be stored at temperatures below 86 F (30 C) and never in direct sunlight.

CERTIFICATION OF CHEMICAL DETECTOR TUBES

Before September 1985, many chemical detector tubes were certified by NIOSH. The NIOSH program was designed to

ensure that commercial detector tubes complied with established performance specifications. However, as a result of budget cuts, NIOSH eliminated the certification program for detector tubes. A private organization, the Safety Equipment Institute (SEI) of Arlington, Virginia, filled the void left by NIOSH's departure from the tube certification program. The SEI now certifies detector tube systems through a program similar to that established by the NIOSH, which involves product testing and quality assurance audits conducted by designated, third-party independent laboratories. In fact, the SEI program adheres to the same test standard established by the NIOSH program: Title 42, Part 84 of the *Code of Federal Regulations* (42 *CFR* 84). The SEI offers certification of manufacturers' product models and grants the right to use the SEI certification mark if the testing laboratory has determined that the product models submitted have been tested according to the appropriate standard and the quality assurance auditor has determined that the manufacturer has complied with SEI quality-assurance requirements. The SEI certifies a manufacturer to produce a gas detector tube unit if it meets the minimum requirements set forth in the regulations (basically ±35 percent accuracy at one half the exposure limit and ±25 percent at one to five times the exposure limit). The quality of future production lots is secured by a quality assurance plan, which the SEI approves as part of the certification process. Adherence to the quality assurance plan is verified by periodic plant inspections and by testing samples obtained from actual inventory.

Other Colorimetric Direct-Reading Devices

Both passive and active colorimetric indicator badges rely on the contaminant gas or vapor reacting with an indicating reagent to yield a uniform color change in the reactive portion of the badge. In some devices, the color changes as a function of time as well as concentration, so the user must note the duration of exposure and refer to a plot of color intensity versus time for a given concentration of the contaminant. The color may be compared against a color comparator, which provides a reference color intensity for a given number of ppm-hours. Some badges have the color comparator built into the badge, while others require a separate color-comparing card. Other badges simply show a color change at a specified ppm-hour exposure that is identified on the card. Knowledge of the exposure time, in the latter case, will provide an estimate of time-weighted average concentration. In a passively sampled badge, the ambient air diffuses up to the surface of the device and reacts to form the color. Passive-sampling indicator badges are currently available for at least 28 different compounds, including ammonia, carbon monoxide, glutaraldehyde, ozone, phosgene, and toluene diisocyanate (TDI). In an actively sampled badge, air is drawn though a chemically treated porous paper, with a sampling pump, for a fixed time period and a color appears if the contaminant is present. A color comparator is used to estimate the concentration of the contaminant. A relatively smaller number of actively sampled colorimetric badges are commercially available, for several isocyanates, in particular.

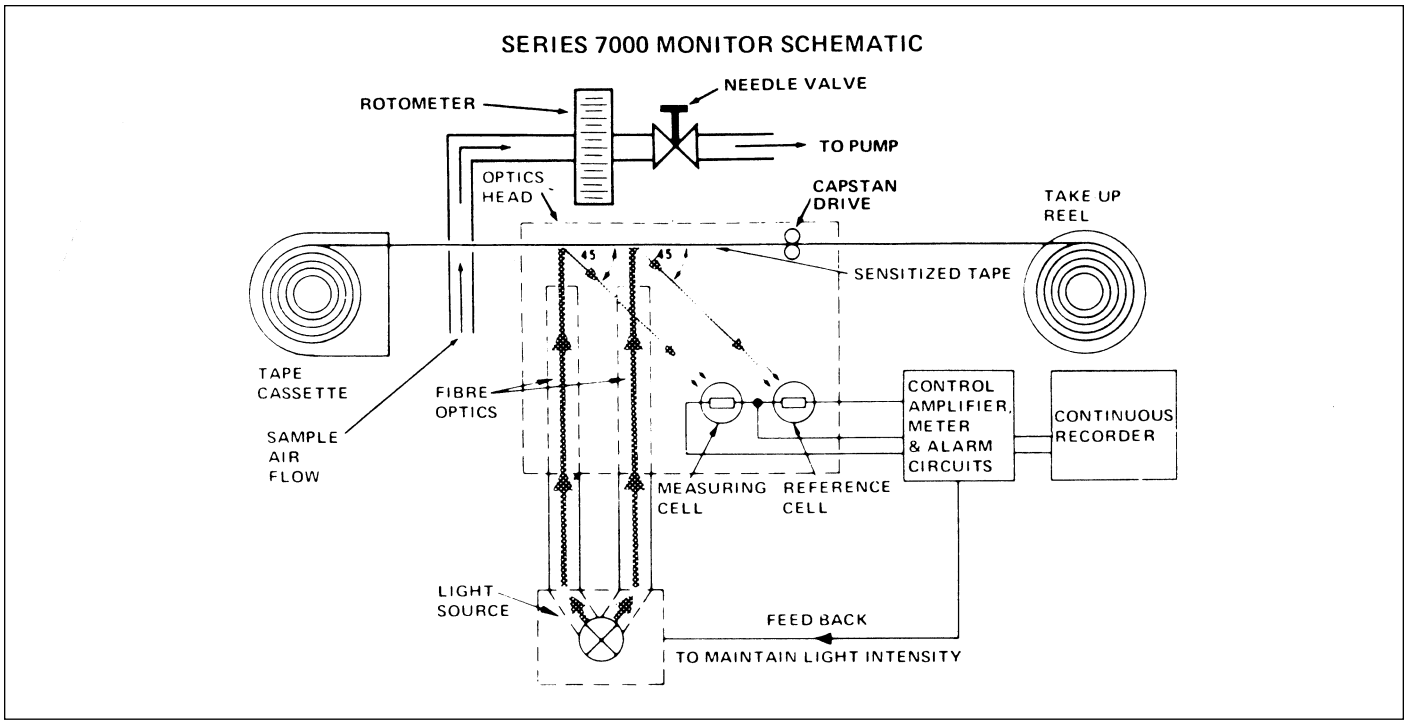

Figure 17–16. A schematic diagram of a colorimetric paper tape area monitor usable for a number of different compounds. (Courtesy MDA Scientific, Inc.)

COLORIMETRIC TAPE SAMPLERS

Another device that uses the color change resulting from a chemical reaction to measure air contaminants is a colorimetric tape sampler. In modern devices, a chemically treated paper tape is drawn at a constant rate over the sampling orifice; the air contaminant drawn through the tape reacts with the chemical to produce a stain. The intensity of color is directly related to the concentration of the contaminant and is read optically and then displayed on a digital readout. Chemically impregnated paper tape devices have been in use since the early 1950s. The first units were developed to detect hydrogen sulfide (H_2S). A filter paper was impregnated with a lead acetate solution that produced a dark stain (lead sulfide) when exposed to H_2S. The concentration of H_2S was then determined by measuring the transmission of light through the stained paper.

Light of equal intensity (from a common source through matched fiber optics) is directed to both the top and bottom track and measured by a set of matched photoelectric detectors mounted at an angle of 45 degrees. The difference in reflected light is then measured. The system thereby compensates for slight tape variations. This is illustrated in Figure 17–16, which schematically illustrates the general principle of operation. This diagram also shows the capstan-driven cassette, which moves the impregnated paper tape past the exposure orifice and readout section of the optical block and gate assembly. The manufacturer of this particular instrument markets 20 different impregnated tapes, for compounds ranging from aliphatic amines/ammonia to sulfur dioxide.

Another type of direct-reading colorimetric monitor, used for monitoring TDI or methylene diisocyanate (MDI), is shown in Figure 17–17. Field calibrations can be accomplished at any time by use of a test strip provided with each monitor.

Figure 17–17. A direct-reading, hand-held paper tape instrument for monitoring certain isocyanates. (Courtesy GMD Systems, Inc.)

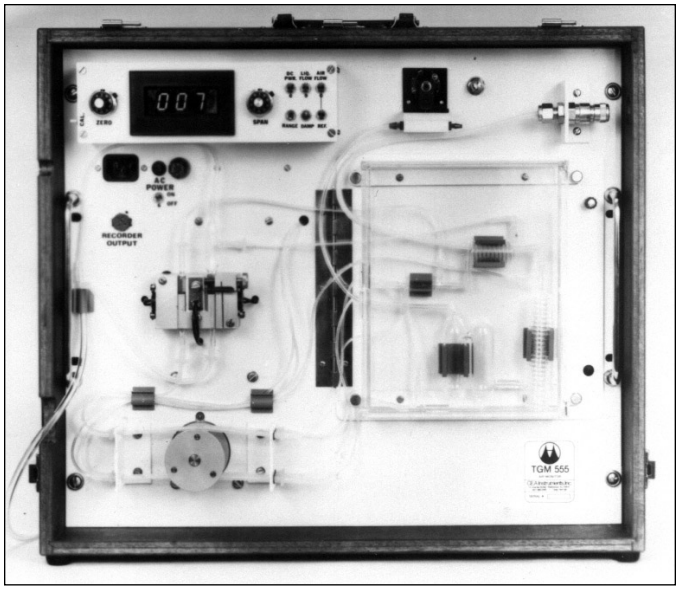

Figure 17–18. A portable colorimetric analyzer that can be configured to analyze 16 different compounds. (Courtesy CEA Instruments, Inc.)

The strip has calibrated stains that are equivalent to the stains produced by known concentrations of the contaminant.

COLORIMETRIC ANALYZER

One somewhat unusual direct-reading instrument is a colorimetric analyzer that takes advantage of the color-producing reactions of a number of airborne contaminants with appropriate reagents (Figure 17–18). The air is drawn into a trapping solution and mixed with the appropriate reagent, and then the colored species produced is analyzed photometrically and a digital readout provided. Each compound has a different reagent system associated with it, and the flow pattern may vary depending on the nature of the compound. Such instruments currently are capable of analyzing at least 16 different compounds.

MONITORS INTENDED FOR A BROAD RANGE OF COMPOUNDS

Biosensors

Although at this moment there are no direct-reading instruments based on biosensors that are commercially available, there most certainly will be before this edition of *Fundamentals of Industrial Hygiene* is revised. The industrial hygienist should be alert to the possibilities they will offer. These devices are based on the principle of immunoaffinity, in which a molecule built into the sensor will uniquely conjugate with a single, specific molecule and then be quantitated by another technique. By extracting antibodies to a specific compound, and immobilizing them on the sensor, one should be able to refine this technique to apply to a variety of molecules, particularly more complex ones.

An example of this is a fluorimetric affinity biosensor developed by Johns Hopkins University. This device has

Figure 17–19. A portable volatile organic compound monitor using a photoionization detector. (Courtesy Photovac International, Inc.)

shown itself capable of measuring 0.1 parts per billion (ppb) (w/w) of aflatoxin in water in a period of less than two minutes. Air samples run through an impinger could be quantitated in nearly real time to determine the aflatoxin concentration. The developers assert that this technique can be extended to pesticides, polynuclear aromatic hydrocarbons, toxins from various bacteria, drugs of abuse, chemical and biological warfare agents, and metabolites of chemical compounds found in the human body. Such a device could make a dramatic impact on the industrial hygienist's ability to quantitate low concentrations of some highly toxic agents.

Nonspecific Detectors

A number of direct-reading instruments are not compound-specific or are specific for whole classes of compounds. These are of value as leak detectors or in atmospheres that are known to contain only a single contaminant. Nonspecific instruments used for detection of airborne contaminants include devices that contain flame ionization, photoionization, electron capture, and thermal conductivity detectors. The first three types rely on ionization of the contaminant molecules to produce a response. These detectors measure airborne contaminants directly and can be used alone, but are often used in conjunction with a gas chromatograph that separates multiple air contaminants.

FLAME IONIZATION DETECTORS

Flame ionization detectors are highly sensitive to compounds that ionize in the presence of an oxyhydrogen flame. The ions are collected and the electric current generated for the compound of interest (whose response factor has been determined) can be translated into a concentration. Organic compounds that have a large number of carbon–hydrogen bonds are detected with great sensitivity with flame ionization detectors, but as the number of C–H bonds decreases (for example, with chloroform [$CHC1_3$]), the sensitivity decreases.

PHOTOIONIZATION DETECTORS

Photoionization detectors are sensitive to compounds that are ionized by certain wavelengths of ultraviolet light. The ions produced by the ultraviolet lamp in a photoionization detector are collected and this current is translated electronically into a signal that can be read on the instrument (Figures 17–19 and 17–20). Aromatic hydrocarbons are particularly sensitively detected with a photoionization detector. There are several different wavelengths of ultraviolet lamp available for some direct-reading photoionization detectors, which can introduce some selectivity into the detection. Stable air constituents such as oxygen and nitrogen are not ionized by photoionization detectors. Most hydrocarbons (except methane) cause a response on a photoionization detector. Photoionization detectors respond to water vapor, so changes in absolute humidity between where the instrument was calibrated and where it is used could introduce errors into the measurement.

ELECTRON CAPTURE DETECTORS

An electron capture detector relies on the ability of the compound of interest to capture primary and secondary electrons

Figure 17–20. A portable hydrocarbon analyzer that uses a photoionization detector. (Courtesy Sentex Systems, Inc.)

from a small radioactive source (typically tritium, ^{3}H, or ^{63}Ni) and thus attenuate a current flowing from the radioactive source to a collector electrode. The electronegativity of the elements (the most electronegative elements are in the upper-right portion of the periodic table) that make up the compound determines the sensitivity of the electron capture detector to the compound. Thus, halogen-containing compounds, as well as those containing nitrogen or oxygen, are detected with high sensitivity by an electron capture detector. Portable or transportable electron capture detectors are used to evaluate fume hood performance through the release of sulfur hexafluoride (SF_6) at the face of the hood. Sampling points outside the hood draw air samples into the electron capture detector, which indicates the hood's capture efficiency by comparing the external concentration of SF_6 with its internal concentration.

THERMAL CONDUCTIVITY DETECTORS

Thermal conductivity detectors rely on the change in the ability of contaminated air to transmit or conduct thermal energy. Air with the contaminant is passed over one leg of a Wheatstone bridge in which the filaments are heated by a current flowing through them. (See the section on combustible gas meters for more details.) The change in thermal conductivity of the measurement leg versus the reference leg causes a change in temperature in one leg, inducing an imbalance in the bridge circuit and a resultant measurable electrical voltage. This can be translated into a concentration for a known contaminant.

Spectrophotometers and Spectrometers

A number of direct-reading instruments are based on the characteristic absorption of electromagnetic, ultraviolet, visible, or infrared radiation. Devices used to measure many organic compounds and mercury vapor are based on this principle.

INFRARED ANALYZERS

Many gases and vapors, both inorganic and organic, absorb certain characteristic frequencies of infrared radiation. This property and the resultant infrared spectrum can be used to identify and quantify compounds in the air that absorb in the infrared region. This includes most compounds except the diatomic molecules of hydrogen, nitrogen, and oxygen. An infrared source in the analyzer emits the full frequency range of infrared radiation. The window material in the cell may absorb certain frequencies, and thus limits the frequencies that can be used. In a dispersive instrument, the radiation is separated into its component wavelengths with a prism or grating and the desired wavelengths are directed through the sample and onto a detector. In a nondispersive instrument, the infrared radiation is passed through a filter, then through the air sample and onto a detector.

In a double-beam instrument, the infrared energy passes through two cell paths simultaneously. At the opposite end is a detector that measures the energy transmitted through the two cells. One of the cells is the sample cell. The other is a sealed comparison cell with a special mixture inside. If the gas in the sample cell contains a gas that absorbs energy at the selected frequency, then the detector will detect less energy coming through the sample cell than through the comparison cell. The detector emits an electrical signal to alert the user to this imbalance. The same would be true with a single-beam instrument, but the infrared absorption background of uncontaminated air would not be subtracted out of the signal.

Figure 17–21. A portable, direct-reading instrument with an infrared spectrophotometer. (Courtesy The Foxboro Company.)

One battery-operated portable instrument can generate an entire infrared spectrum and has a preprogrammed library of compounds in its memory, so that the instrument automatically determines the correct wavelength to monitor for the compound of interest (Figure 17–21).

When a single contaminant is present, identification and measurement are achieved easily. Lightweight instruments using filters are available for single specific compound detection. When a number of absorbing contaminants are present, separation of the contaminants may not be possible, depending on the differences in infrared absorption spectra among the compounds of interest. If the spectra do not overlap significantly, analysis of multiple compounds in the same sample, and thus compound specificity, is possible, especially with a dispersive instrument with a much narrower bandwidth.

FOURIER-TRANSFORM AND OPEN PATH INFRARED SPECTROSCOPY

Fourier-transform and open path infrared analysis of workplace air in real time have become realities for the industrial hygienist. Although no discussion of the principles of Fourier-transform infrared (FTIR) spectrophotometer, compared to a prism or grating infrared instrument, will be made here, suffice it to say that an FTIR spectrophotometer can do a complete scan of a wide range of infrared wavelengths in a second or two and has

Figure 17–22. An open path infrared analyzer. (Courtesy Zellweger Analytics, Inc.)

a much higher resolution than a grating infrared spectrophotometer. The characteristics allow this instrument to quantitate a large number of different chemical compounds in a complex gas sample. This is a very specific requirement that the industrial hygienist encounters occasionally. A direct reading FTIR spectrophotometer is commercially available for doing monitoring of complex gas mixtures. The instrument requires 115 V AC, and weighs about 17 kg, which makes it readily transportable. An external personal computer is required for instrument readout, and for doing the data analysis and compound identification required, which could add another 2–5 kg to the weight.

A relatively recent development is an open path infrared analyzer used for airborne monitoring some distance away from the device (Figure 17–22). In these instruments, there is no gas cell in which the contaminant is measured, but rather the open air is the environment in which the measurement is made. The transmitter and receiver of the infrared radiation may be built into one device, with a remote mirror reflecting the signal back, or else the transmitter and receiver of the infrared radiation may be separated by a considerable distance. This device is intended for the detection of major leaks or spills of combustible or toxic gases within a distance of roughly 200 m. It can have either a local or remote, digital or analog output in order to get a readout of the actual concentration of the contaminant of interest. The response time is less than 3 seconds, making it a truly real time monitor for major spills. The sensitivity of the open path infrared analyzer—and thus the maximum distance over which it can measure—depends on the intensity of the infrared absorption by the compound(s) of interest.

PHOTOACOUSTIC SPECTROMETERS

Direct-reading instruments that are not yet portable or battery-operated, but are readily transportable, are photoacoustic spectrometers (Figure 17–23).

The instruments rely on the absorption of a characteristic band of wavelengths of infrared radiation within the detector cell. The absorption of the infrared radiation causes slight heating, and thus expansion, of the gas contained in the cell. The measurement of the change of pressure in the cell is translated into a concentration of the contaminant present in the cell. The measurement is specific only if no other contaminant present absorbs infrared radiation significantly in the same band of wavelengths.

Surface Acoustic Wave Detectors

A new type of sensor that is relatively simple and rugged is the surface acoustic wave sensor. The basic principle is that acoustic waves are transmitted at a resonant frequency into a piezoelectric material. This material can be coated with a variety of different absorptive polymers. The resonant frequency is determined by the mass of the vapors present in the air that are absorbed by the polymer. Changes in that frequency can be measured and translated into a signal which is proportional to the concentration of a particular contaminant in the air. A transportable gas chromatograph using surface acoustic wave detection is currently on the market and claims to have low ppb limits of detection for most compounds.

Multisensor Arrays

A long-term goal of direct-reading instruments is the ability to have a high degree of specificity (i.e., the ability to distinguish one compound among many present in the air) as well as sensitivity, but at the same time be relatively lightweight, rugged, and inexpensive. Instruments using multisensor arrays are moving in that direction. Arrays of polymer-coated surface acoustic wave sensors, carbon-loaded polymer coated chemiresistors, tin oxide sensors, and conducting polymer sensors have all been used to create detectors that have a high degree of accuracy in identifying

Figure 17–23. A transportable, direct-reading photoacoustic spectrometer using 115 V AC power. (Courtesy California Analytical Instruments, Inc.)

and quantifying one in a mixture of four different vapors. This is done by training the instrument to recognize the different signal patterns arising from the sensor array associated with each contaminant.

Gas Chromatographs

Chromatography is a method of separating complex mixtures. In gas chromatography, the components of a volatile mixture migrate differentially through a separating column, transported by a carrier gas passing through the column. The extent of separation depends on the chemical and physical properties of the molecules being separated, the nature of the separating column, its temperature, and the flow rate of the carrier gas. Optimally, differential migration takes place and each component separates as a discrete substance. Detection of the separated components takes place as the carrier gas emerges from the column. Detectors used for portable gas chromatographs include flame ionization, photoionization, electron capture, argon ionization, flame-photometric, and thermal conductivity detectors. All but the argon ionization and flame photometric detectors are described in the section of this chapter on nonspecific detectors.

Argon ionization detectors rely on a somewhat more complicated energy transfer process to form ions. Argon gas, used as a carrier gas for the gas chromatograph, is electronically excited by decay of a radioactive material in the detector. This produces electrons that are accelerated to excite the Ar atoms to a particular higher-energy state. Collisions between the contaminant and the excited Ar atoms result in a transfer of energy from the Ar atom to the contaminant, resulting in ionization of the latter. The ions formed from the contaminant are collected and the resulting signal is translated into an instrument response.

Flame photometric detectors are based on the emission of certain wavelengths of light by an element introduced into a flame. Flame photometric detectors are generally used to detect compounds containing sulfur. Sulfur emits characteristic wavelengths of light in the range of 300–423 nm when heated to high temperatures; this light, passed through an optical filter or prism, generates a signal in a photosensitive detector. The intensity of the signal is related to the amount of the element in the flame.

Quantitative analysis for a specific component requires separation of the component from other compounds in the sample and identification and quantitation using a calibrated detector. The use of retention time (the length of time required for a compound to pass through the chromatographic column) is a common, though somewhat ambiguous, means of identification. If the possible components of the atmosphere being analyzed are understood, then misidentification possibilities are minimized. Calibration of the detector requires the introduction of known amounts of the compound into the detector and the determination of the relationship between the amount introduced and the instrument response.

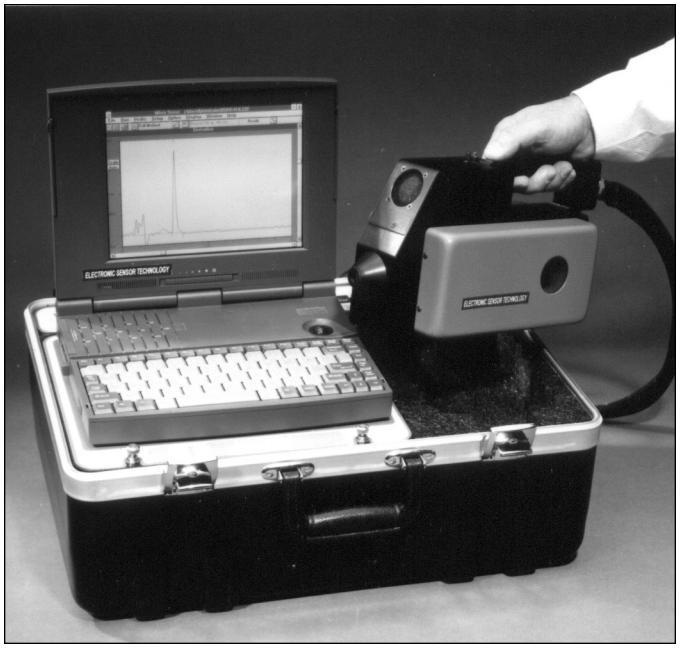

Figure 17–24. A hand-held, preprogrammed gas chromatograph that uses a surface acoustic wave detector. (Courtesy Electronic Sensor Technology.)

Portable gas chromatographs may involve sample injection directly from the air, thermal desorption from a solid sorbent or preconcentration from an air sample followed by thermal desorption. Column backflush capability also exists, as do instruments that are preprogrammed for a specific group of compounds. Preprogrammed instruments recognize the retention time for a given compound and apply a predetermined response factor to that compound, giving a direct reading of airborne concentration. Instrument reliability, ease of operation, ease of calibration, and instrument reliability are key considerations when defining the minimum technical skill required to operate the device. Two types of portable gas chromatographs are shown in Figures 17–24 and 17–25.

Portable Gas Chromatographs/ Mass Spectrometers

In the past, gas chromatographs combined with a mass spectrometric detector have been powerful laboratory tools for the identification and quantitation of airborne contaminants in multicomponent mixtures. Now such a combination is available in a portable, battery-operated instrument that can be taken into the field. The manufacturer indicates that the instrument has been designed for harsh environments and rough handling, intended for field work associated with hazardous waste site or emergency response monitoring, among other things. Using a mass spectrometric detector in comparison to other detectors that have been used for portable gas chromatographs is advantageous, since the former has the ability to identify compounds in an unknown mixture by matching the fragmentation pattern of the unknown peak with that of knowns stored in a portable computer-based library.

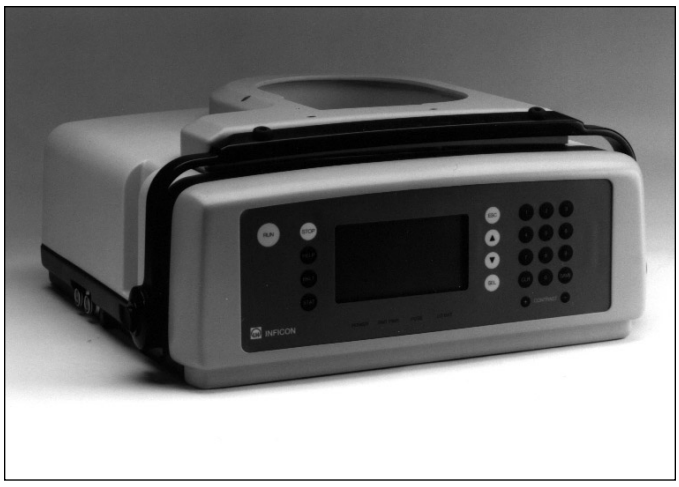

Figure 17–25. A field-portable HAPSITE® gas chromatograph-mass spectrometer. (Courtesy INFICON.®)

Figure 17–26. A portable TDI monitor based on the principles of ion mobility spectrometry. (Courtesy Graesby Environmental, Atlanta, Ga.)

Ion Mobility Spectrometer

A relatively new device available for air contaminant monitoring is the ion mobility spectrometer (Figure 17–26).

In this device, ion-molecule reactions are initiated by the electrons emitted from a radioactive ^{63}Ni source. Using an electric field to separate out ions of a certain charge before they recombine, the instrument injects these ions into a drift region, where they are separated by the time-of-flight through that region and then migrate to a collector electrode. The migration is related to the mass and size of the species and the temperature and pressure. This type of instrument was developed for rapid detection of toxic gases in combat situations, but is now used for the monitoring of other gases in the workplace. The instrument can be programmed for any number of compounds, but is extensively used for toluene diisocyanate (TDI) monitoring because of the ceiling occupational exposure limit for this compound and the rapid response of the ion mobility spectrometer.

Particulate Monitors

Several types of direct-reading monitors are used to measure airborne particulate concentrations. More precisely, these devices are generally aerosol monitors in which the aerosol is a solid (dust), liquid (mist), or condensed vapor from a high-temperature process such as combustion or welding (fume). Most of these devices are based on the light-scattering properties of particulate matter, and are sensitive to the size, shape, and refractive index of the particles (Figure 17–27).

The light source could be monochromatic or polychromatic, using either visible or infrared radiation, and the scattered light detector could be a photomultiplier tube, photodiode, or infrared detector. Most instruments have a pump that draws a sample into the sensing volume, but there are some in which convection is relied on to do that. The instrument must be calibrated with particulates of a size and refractive index similar to those to be measured in the ambient air. If this is not done, the results indicated on the instrument could easily be off by an order of magnitude or more.

Another type of particulate monitoring device relies on the behavior of a piezoelectric crystal. The frequency of the crystal's oscillations is changed by the amount of particulate matter deposited on it when it carries an electrostatic charge (Figure 17–28).

After the sampling period is complete, the concentration of dust is displayed and the crystal is automatically cleaned and ready for the next cycle. The instrument measures particles ranging in size from 0.01 to 3.5 μm. (An inertial impactor in the device eliminates particles of larger size.)

CONDENSATION NUCLEI COUNTERS

This type of particulate monitor is highly sensitive and is used as a direct-reading instrument for the evaluation of fit factors in air-purifying respirators. This device is based on

Figure 17–27. A direct-reading aerosol monitor using near-infrared light scattering to detect particles. (Courtesy MIE, Inc.)

Figure 17–28. A direct-reading particulate monitor using a piezoelectric crystal for detection. (Courtesy TSI Incorporated, St. Paul, Minnesota.)

the ability of small concentrations of dust particles to serve as condensation nuclei, that is, solid centers on which supersaturated vapors can condense to form droplets. If particulate matter is drawn into a vapor that is supersaturated with ethanol, these condensation nuclei will form and can be detected through light-scattering measurements. The technique is very sensitive, and thus ambient concentrations of dust (and their reduction on the inside of a respirator worn by a test subject) can serve as a measure of the fit factor of the respirator. This particulate measurement technology has proven to be very useful in doing quantitative fit testing of respirators rather than using the older technology of generating a much higher concentration of aerosol particles in a test chamber and putting the subject to be fit-tested in that chamber.

FIBER MONITORS

Certain types of particle counters measure the light scattering from a single particle at a time. Taking advantage of the fact that the light scattering from fibers is different than that from nonfibrous particulate matter, a manufacturer has developed an instrument that distinguishes, to some extent, between these two types of airborne particulate matter and quantitates the fibrous particles. This device seems to have some bias, as well as time-dependent responses, and potential users are cautioned to compare such instrument results with those obtained by traditional filter-counting techniques using phase-contrast microscopy in order to validate any results.

Calibration

All instruments used for sampling and analysis of gases, vapors, or particulates must be calibrated before use, and their limitations and possible sources of error must be fully understood. It is very important to establish that an instrument responds properly to the substance it is designed to sample. This is generally carried out by performing calibration procedures with standard concentrations of the substance of interest. In the case of particulate monitors, it may require a standard particle size, as well.

There are a number of commercially available static-type calibration kits for combustible and toxic gases. Typically, they contain gases that can be used for both types of instruments. These kits generally contain one or more cylinders filled with a known concentration of a specified gas-air mixture, a regulating valve, a pressure gauge for measuring the pressure in the container, and a hose adapter that connects the cylinder to the instrument to be checked (Figure 17–29).

Once the container kit is attached to the instrument, a sample of the gas-air mixture from the container is permitted to flow into the device. The meter reading of the instrument is then compared with the known concentration of the sample to verify the proper response.

A somewhat more difficult way of calibrating gas or particulate detection instruments requires the generation of the desired mixture by adding the desired contaminants in a known quantity to a known quantity of air. The rate of airflow and the rate at which the contaminant is added to the sample stream must be carefully controlled in order to produce a known dilution ratio. Dynamic systems offer a continuous supply of contaminant, allow for rapid and predictable concentration changes, and minimize the effect of wall losses as the test substance comes into equilibrium with the interior surfaces of the system. A permanent record should be maintained of all calibration procedures, data, and results. The information to be kept for this record includes instrument identification, temperature, humidity, trial run results, and final results. It is important that the operator thoroughly understand how to operate the instrument and

Figure 17–29. A calibration test kit for calibrating combustible gas and toxic gas sensors or instruments. (Courtesy MSA.)

know the instrument's intended use and the calibration procedures recommended by the manufacturer.

Performance Evaluations and Instrument Specifications

New direct-reading instruments come on the market with some frequency, and third-party organizations exist which evaluate instruments with regard to their claimed performance specifications and with regard to other instruments that are similar or identical in function. The National Institute of Occupational Safety and Health (NIOSH), at Morgantown, West Virginia, has established a new Health Effects Research Laboratory that has among its goals to develop and evaluate real-time personal and area direct-reading instruments for chemical, physical, and biological agents. The reader should watch for relevant reports coming from this laboratory related to the evaluation of direct-reading instrumentation. Knowledge of the performance specifications of a particular instrument can be of value, but knowing that an instrument complies with one or more of the existing standards is also of considerable value.

In the United States, the American National Standards Institute (ANSI) and the Instrument Society of America (ISA) have established a number of performance requirements for various direct-reading instruments. The interested reader is directed to their Web sites (e.g., http://www.ansi.org/public/std_info.html) to find information on available standards. In Europe, both the International Electrotechnical Commission (IEC) and the European Commission for Electrotechnical Standardization (CENELEC) have established performance standards for direct-reading instruments. Information about CENELEC standards can be obtained from their Web site (http://server.cenelec.be), while information about IEC standards can be obtained from their Web site (http://www.iec.ch).

Electromagnetic Susceptibility

In this era of increased telecommunications, users of direct-reading instruments must be on the alert for instruments whose performance is influenced by cell phones, two-way radios, and other forms of communication equipment, as well as by other electromagnetic fields. In past years, a number of different instruments were shown to give erroneous responses during transmission or reception of radiocommunications of various kinds in the vicinity, so-called electromagnetic susceptibility. This could be more of a problem when the industrial hygienist is not directly reading the instrument, but the instrument has a data-logging device. In the latter case, the correlation between radiofrequency signals and anomalous instrument response might be less obvious. Purchasers of new or unfamiliar equipment should always inquire about the instruments' resistance to such electromagnetic fields. OSHA's Cincinnati Laboratory has generic electromagnetic susceptibility specifications that can be requested by telephone at (513) 684-3721.

SUMMARY

The ultimate goal of the hazard evaluation process is to determine the exact amount of vapor, gaseous, or particulate contaminants present in the work environment. Proper operation of direct-reading instruments used in hazard evaluation is essential to ensure that the information obtained is accurate enough to provide a useful interpretation. Faulty operation of air-sampling instruments can result in either high or low readings. Low readings could falsely indicate that no hazard is present when dangerous conditions might exist; conversely, high instrument readings could lead to the implementation of unnecessary control measures.

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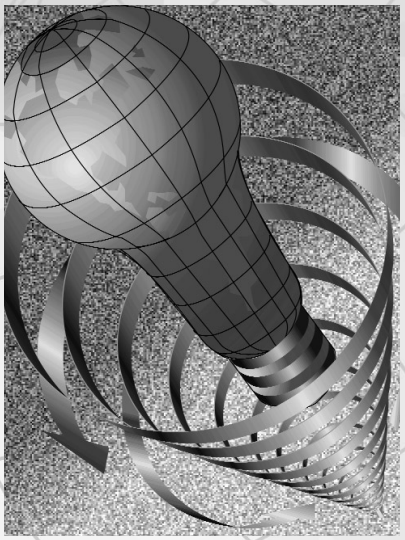
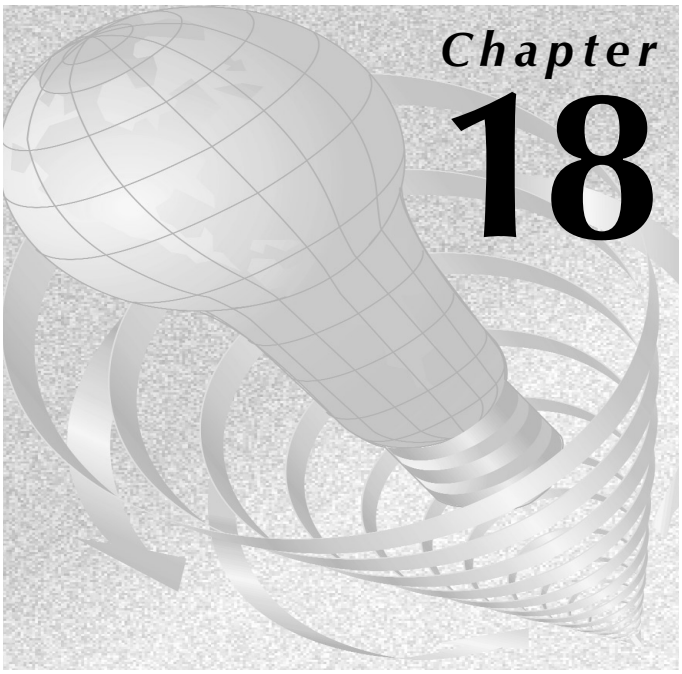


Control of Hazards

Part V



Chapter 18

Methods of Control

by Susan M. Raterman, CIH, REPA

The general principles and methods involved in controlling occupational health hazards will be discussed in this chapter. In the field of industrial hygiene, the objective of occupational health hazard control is to ensure that employees' exposure to harmful chemical stresses and physical agents does not result in occupational illness. The quantities of interest that must be measured are the concentration or intensity of the particular hazard and the duration of exposure.

The types of industrial hygiene control measures to be instituted depend on the nature of the harmful substance or agent and its routes of entry into the body. An employee's exposure to airborne substances is related to the amount of contaminants in the breathing zone and the time interval during which the employee is exposed to this concentration. Reducing the amount of contaminant in the employee's breathing zone or the amount of time that an employee spends in the area will reduce the overall exposure.

With employment in the United States shifting from manufacturing to the service sector, many workplaces today present nontraditional occupational health hazards. Industrial hygienists need to possess the skills to implement control methodology in both traditional industrial settings and workplaces such as laboratories, offices, construction sites, and environmental hazard remediation projects. This requires an understanding of the toxicology of a broad range of potential hazards, including biological agents, chemicals, construction materials, and physical stressors, as well as an understanding of process technologies and work practices. A complete understanding of the circumstances surrounding an exposure hazard is required in choosing methods that will provide adequate control. To lower exposures, the industrial hygienist must first determine the contaminant source, the path it travels to the worker, and the employee's work pattern and use of protective equipment (Figure 18–1).

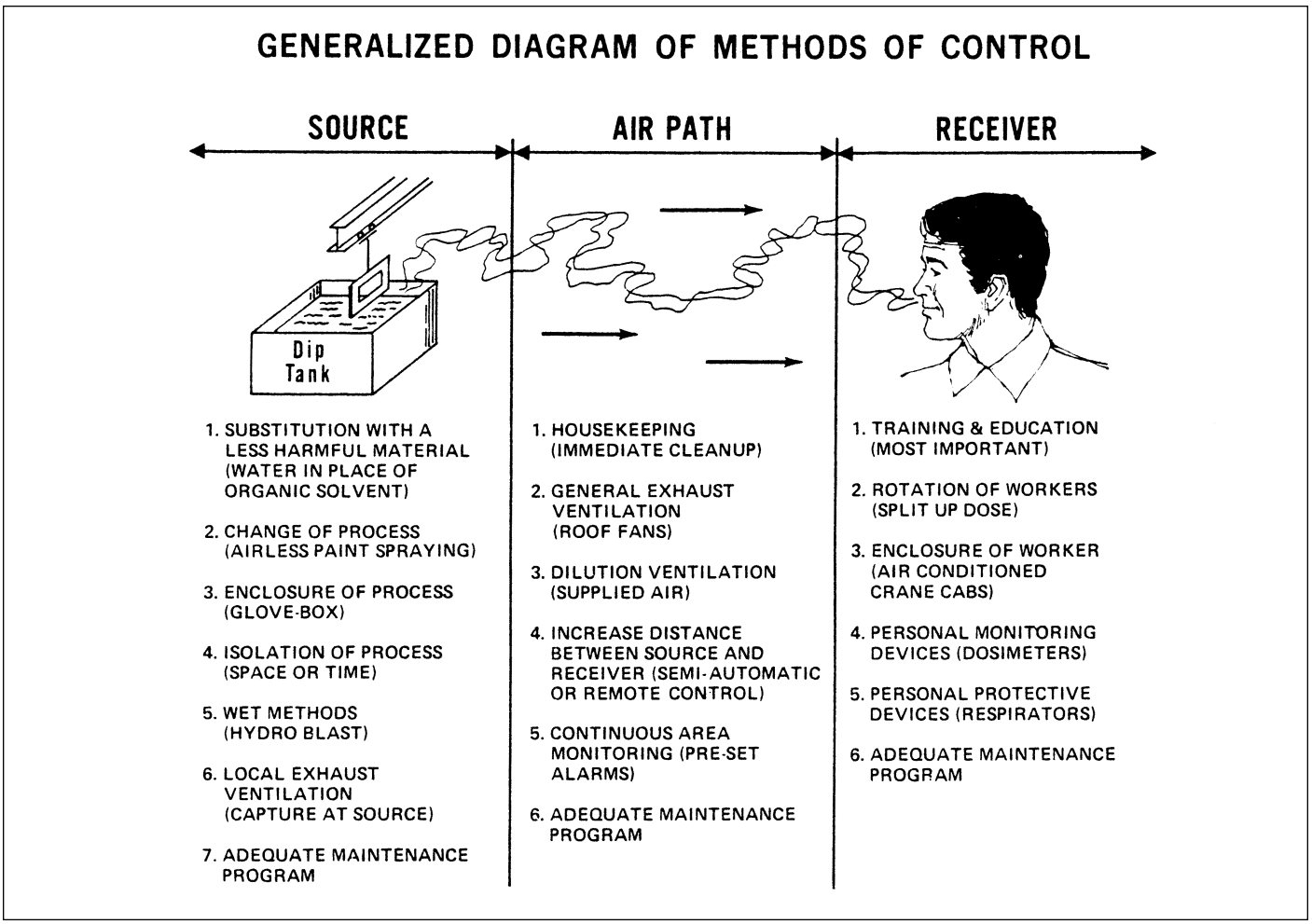


Figure 18–1. To determine the extent of exposure, locate the contaminant source, its path to the employee, and the employee's work pattern and use of protective equipment.

Hazards can change with time, so health hazard control systems require continuous review and updating.

METHODS OF CONTROL

The methods of control of health hazards in the work environment are divided into the following categories:

- ➢ Engineering controls, which remove or reduce the hazard either by initial engineering design specifications or by applying methods of substitution, isolation, or ventilation.
- ➢ Administrative controls that minimize employees' exposures by scheduling reduced work times in contaminant areas, good work practices, and employee training. Appropriate training includes hazard recognition and work practices specific to the employee's job that can help reduce exposures.
- ➢ Personal protective equipment, which employees wear to protect them from their environment. Personal protective equipment can be used in conjunction with engineering controls and other methods of control.

Engineering controls are to be used as the first line of defense against workplace hazards wherever feasible. Such built-in protection, inherent in the design of a process, is preferable to a method that depends on continual human implementation or intervention. The federal regulations, and their interpretation by the Occupational Safety and Health Review Commission, mandate the use of engineering controls to the extent feasible, and if these are not sufficient to achieve acceptable limits of exposure, the use of personal protective equipment and other corrective measures may be considered.

Engineering controls include ventilation to minimize dispersion of airborne contaminants, isolation of a hazardous operation or substance by means of barriers, and substitution of a material, equipment, or process to provide control of a hazard. Although administrative control measures can limit the duration of individual exposures, they are not generally favored by employers because they are difficult to implement and maintain. For similar reasons, control of health hazards by using respirators and protective clothing is usually considered secondary to the use of engineering control methods.

ENGINEERING CONTROLS AT DESIGN STAGE

The best time to introduce engineering controls is when a facility is in the design phase. At that time, control measures can be integrated more readily into the design than after the facility has been built or the processes are on-line.

The systematic layout of the physical building, processes, and systems should comply with occupational safety and health standards. What is planned must be reconciled with what is permissible by law or advised by consensus standards. In any particular situation, jurisdiction and applicability of standards may become complex. When more than one agency or standard is involved, the more stringent standard can be assumed to be controlling. Consideration should be given to specifying design criteria that comply with proposed standards that may take effect after the facility goes on-line.

It is becoming increasingly common for facility and design engineers to consult with the industrial hygienist at the design phase of a new facility or process. Including industrial hygiene control measures at this point can be less costly than adding them later in the construction process. During the design phase, the proposed facility layout must be characterized with respect to construction type, proposed activities in all areas, and possible health hazards. The influence of one area on another and one work activity on another must be assessed. At this point, ergonomic concerns must be identified and corrected with proper workstation design (see Chapter 13).

In terms of the building structure, it is important that the design specifications contemplate the control of moisture to minimize the likelihood of microbial growth. Microbial organisms can adversely affect indoor air quality and cause toxic or allergic responses among building occupants. Proper design of the building envelope and control of indoor relative humidity and the accumulation of condensation on HVAC equipment components will limit the availability of moisture necessary for the growth of microorganisms (ACGIH, *Bioaerosols: Assessment and Control*, 1999). It is also important to evaluate the finished materials within a facility for their propensity to generate hazardous air contaminants. For example, the installation of new carpets, flooring materials, adhesives, and paints can generate volatile organic compounds in concentrations that could result in respiratory and eye irritation in the building occupants.

When air contaminants are created, generated, or released in concentrations that can injure the health of workers, ventilation is the usual method of providing protection. However, other methods of protection should be investigated; one example is automatic operations.

Ideally, operations should be conducted in entirely closed systems, but not all processes lend themselves to this approach. When closed systems are used, raw materials can be brought to the processing site in sealed containers and their contents emptied into storage tanks or containers, minimizing employee contact with the material being processed.

All systems and components should be designed so that airborne contaminants are kept below their acceptable Threshold Limit Values®(TLVs). Do not permit leaking of toxic chemicals from process equipment, such as pumps, piping, and containers, to the working environment to cause a condition in which the TLVs are routinely exceeded in any location where employees may be present. In industrial settings, isolate process equipment and vent to a scrubber, absorber, incinerator, or particle collector, as applicable. If feasible, remotely control the process from a protected control room.

Some work operations, if conducted separately, do not present a serious hazard, but when combined with other job operations can become hazardous in certain situations. Two types of interrelationships can exist.

The first concerns accumulation, as can arise when additional welding stations are provided in a building of fixed general ventilation or when additional noise sources are added to an already noisy work area.

The second type of interrelationship concerns many activities going on in the same area. Activities that by themselves are safe can become hazardous in certain circumstances. For example, vapor degreasing with chlorinated solvents, even when the airborne concentration of the vapors is within permissible limits, may create major hazards when the activity is near work areas where ultraviolet (UV) radiation (from welding arcs, bright sunlight, or molten metal) exists. The decomposition of these solvents caused by the UV radiation can produce phosgene gas–a potent and toxic eye and lung irritant. Merely maintaining the concentration of solvent vapor below the TLV is not satisfactory. The most positive control is to prevent the chlorinated solvent vapors from entering the welding area in any detectable concentrations. If vapors cannot be reduced to a minimum, the UV field should be reduced to a minimum by shielding the welding arc.

The problem of considering safety and health with activity and workstation relationships becomes difficult when more than three or four activities must be considered, as in laying out workstations for new or relocated manufacturing operations where 20 or more activities might require consideration. Decisions should be made to arrive at either an optimum arrangement or a preferred compromise.

Design

Occupational health hazards can best be minimized by workplace design that controls contaminants as much as possible. This requires close cooperation between the industrial hygienist and the design engineer and architect. The ideal situation would have the principles of health hazard protection so thoroughly ingrained in the design professionals that the health and safety professional need only be a passive reviewer. However, the design team needs the help of the health and safety professional during the design process to make sure that a system can be set up that does not pose safety or health hazards to the operator or facility occupants.

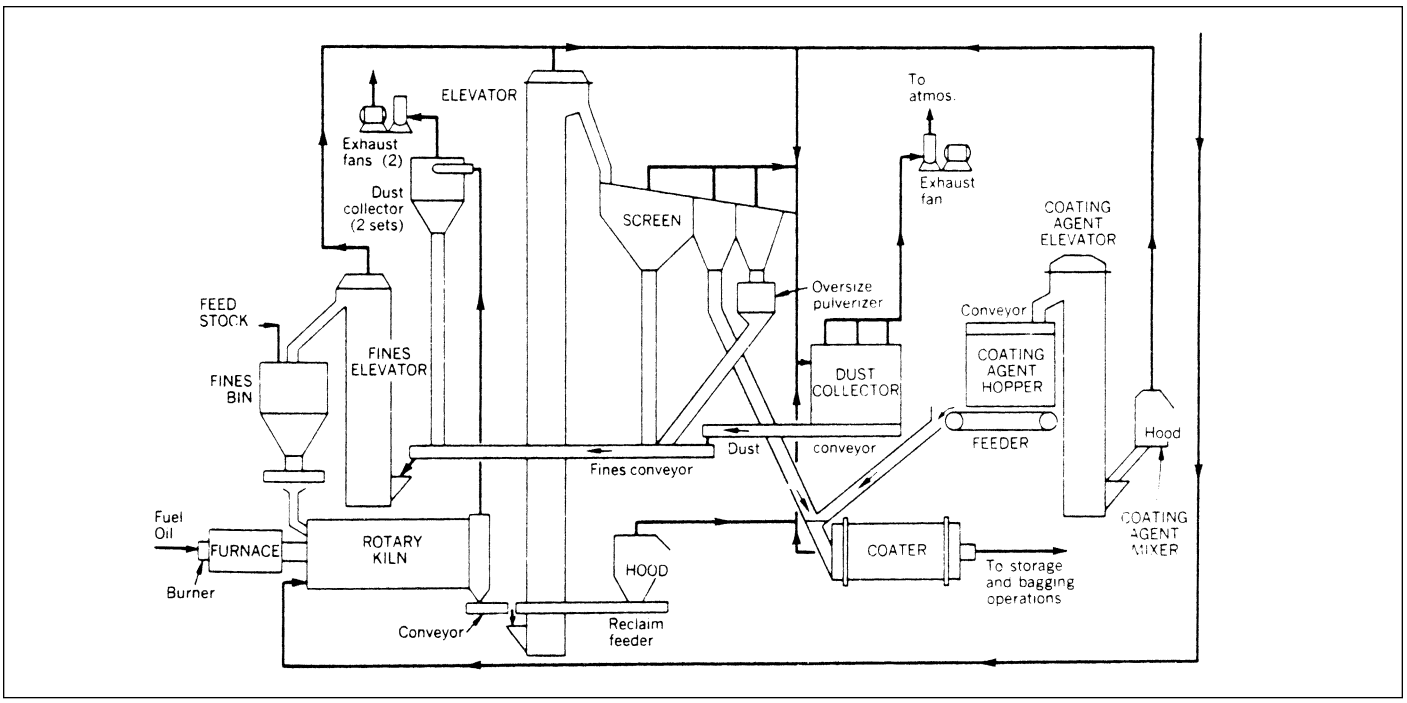


Figure 18–2. A simple process flowsheet showing the stepwise introduction of raw material and the product of each step. The extent of physical or chemical hazards that can occur at any step in the operation should be determined.

Production processes in chemical plants should be designed so that hazardous materials are not released into the environment. It is important to keep the materials and the by-products and wastes within the closed system.

To maintain that integrity, a chemical process flow sheet should be reviewed from an overall material balance point of view (Figure 18–2).

The material that becomes airborne and gets into the work environment to cause problems can be an insignificant fraction of the total amount of material that is circulated through the system, so much so that in a material balance, the quantity of material that is released into the workplace that causes the hazard can be insignificant when compared with the total amount present.

Design factors that should be addressed include the following:

- ➢ To what degree is it possible to remove hazardous residues from a piece of equipment before it is opened?
- ➢ To what extent can a system be designed to be relatively maintenance-free?
- ➢ Can the system be designed so that the entire operation can be conducted as a closed system?
- ➢ Can the process be conducted automatically without worker involvement?
- ➢ Can the system be cleaned automatically without worker involvement?

A design engineer should have extensive knowledge not only of the main aspects of the process being created but also of the finer details, such as health hazard controls and safety devices. Design engineers are usually more familiar with the safety hazards because the effects of their being overlooked are much more obvious that those occurring when health hazards are overlooked.

The same importance should be assigned to minimize contaminant dispersion in other workplace settings such as mixed-use office buildings. The architect and engineer on the design team should address the following factors:

- ➢ Has the building been designed to effectively control moisture and prevent microbial growth on construction materials and in the HVAC system?
- ➢ Are there any activities taking place in the building that use or generate hazardous materials?
- ➢ Is the fresh air intake located away from any contaminant source or air pathway for these contaminant sources?
- ➢ Has the HVAC system been designed to deliver an appropriate volume of air to each occupied space in accordance with the standards of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)?
- ➢ Is local exhaust ventilation required in any special-use areas, such as printing operations, photo developing, welding, or solvent degreasing?
- ➢ Are any special filters required to clean incoming outside air or recirculated air?
- ➢ If tobacco smoking is permitted in the building, is there a separate room with a dedicated HVAC system planned? (See Chapter 21, General Ventilation of Nonindustrial Occupancies.)

When health professionals are involved early in the design process, it is possible to plan the development of sampling

and analytical methods to yield exposure data concurrent with the development of the engineering design. Contaminant monitoring systems can be included as part of the engineering design. Elaborate automated leak-detection systems designed into the process can yield valuable information for evaluating health hazards in the operating unit (Figure 18–3).

Similarly, contaminant monitoring systems can be installed in the ventilation system to alert building engineers of high levels of carbon monoxide or carbon dioxide, which serve as a general indicator of degrading air quality.

Neglect of the health professional-engineer-architect interaction in facility design can lead to major management problems. What could have been an easy solution in the design phase can become an extremely difficult problem later. Changes that might have been readily accomplished during the design phase must now be done as a matter of equipment change and compromise. Worse yet, it may be necessary to shut down production or evacuate employees to correct a hazard that was overlooked. Consequently, management should consider that for certain processes and materials, the initial design of facilities to minimize the health hazards may be a significant and necessary part of the investment.

Maintenance Considerations

It is important to look not only at planned operations but also at the fine details of what is not supposed to be happening. These untoward events may best be described in two general classes.

First, there may be releases of contaminants into the work environment that are relatively continuous, such as flange leaks, exhaust hoods that are not completely effective, pump seals that have weakened, diffusion that occurs along valve stems, or noise emission from leaks in ill-fitting acoustic lagging on a machine. This general class of airborne contaminants or fugitive emissions may have begun as a low-level background that initially was not high enough to be of serious concern. Coupled with this is another kind of episodic exposure. As equipment becomes worn and starts to leak, the general level of background emissions may eventually result in significant worker exposures. Much of this leakage can be dealt with by continuous, careful, intensive maintenance; however, much of it might have been avoided in the initial design. The degree to which any possibility of leakage is engineered or designed out of a system depends to a great extent on how much these potential leaks have been anticipated.

Figure 18–3. This multipoint ambient air monitor is capable of continually measuring up to five gases in as many as 24 remote locations. (Courtesy MSA.)

The second class of emissions of airborne contaminants arises when a closed system or control process becomes momentarily open or uncontrolled. For instance, the lagging has to be removed from the compressor in order to perform some adjustments, or perhaps samples have to be collected or filters replaced. These situations are common in chemical industries. A filter change operation may occur as infrequently as once every six months; however, when problems occur it may have to be done four times a shift. The system has to be designed so that it is possible to clean and purge the filter container so that an employee can perform needed maintenance without hazard.

From time to time, the system as a whole must be shut down for cleaning and purging and afterward opened for maintenance. Under these circumstances, most exposures tend to be brief, but exposure levels can be quite high and may be detected only by closely maintained industrial hygiene surveillance on a day-to-day basis.

Knowledge of the hazards that are present and the potential for the exposure that may exist in an operation gives an industrial hygienist an ideal starting point from which to develop the surveillance program. All too often this step is omitted and the industrial hygienist becomes aware of an engineering project only in the advanced stage of development. Waiting to make changes in the design when the system is about to go to construction can dramatically increase cost.

Design Specifications

The design specifications are the drawings and documents that enable the engineers and architects to precisely define the building, systems, and processes. The industrial hygienist or safety professional should have a clear understanding of where in these specifications health hazards may occur as a result of the process, building materials, or system design.

REVIEW

Before a new operation or process is begun, engineering reviews that go over the whole process should be done to ensure that nothing was forgotten and everything will proceed as planned. Although these reviews are very detailed and time-consuming, it is worthwhile for an industrial hygienist and safety professional to be involved. Sometimes, last-minute changes in the process or equipment are made that can significantly increase or decrease the health hazard.

Figure 18–4. Loading or unloading of tank trucks can release airborne contaminants.

STARTUP

The industrial hygiene surveillance begins when a process is put into operation or a facility is brought on- line and should continue for as long as the operation continues.

When a facility is brought on-line, it is recommended that the ventilation system be operated for 48 hours prior to occupancy to purge construction-related contaminants (ASHRAE, 1995). Air balancing reports for the ventilation system should be reviewed before the building is occupied and processes involving hazardous materials commence. Problems in handling and operating procedures that were not anticipated during the design stage will become apparent when the facility is operational. Prompt correction of these problems is much easier during the early setup phase when procedures and people are still somewhat flexible.

SAMPLE TAKING

In many industrial operations, such as steel mills and petrochemical facilities, taking product samples is a common procedure. The design engineer and the industrial hygienist can choose between a product sampling system that does not provide much control and a system that provides almost total control. Each of these choices probably has some cost increment associated with it. The choice should be based on assessment of the severity of the potential health hazard.

LOADING OPERATIONS

One of the most serious problems in the field of health hazard control is the loading and unloading of tank cars, tank trucks, and barges. Putting a liquid into a space previously occupied by air or vapor quickly saturates that air with vapor. It may become necessary to go to vented systems, enclosed systems, and automatic loading systems that include vapor recovery so that the vapor that is pushed out of the tank will be recovered (Figure 18–4).

Episodic exposures are difficult to control from an engineering point of view. Also, for these infrequent emergency or nonroutine events, personal protection can be the appropriate solution. However, design engineers should recognize that these exposure events will happen, that product samples must be taken, that equipment must be maintained, and that filters must be changed. The industrial hygienist working with the designer must consider how these operations can be conducted so that the worker need not be overexposed.

Hazardous Materials

Some materials must be handled carefully because of their toxicity, flammability, reactivity, or corrosivity. The processes and practices to be used must be consistent with the standards applicable to materials with these characteristics.

Stringent controls regulating mutual proximities, ventilation, sources of ignition, and design are imposed on general industry by federal codes. When potentially photochemically reactive solvents are involved, process controls and discharges to the atmosphere are subject to regulation by air-quality regulatory authorities.

Compressed gas and equipment for its use in industry are extensively referenced in the Compressed Gas Association's standards. Methods of marking, hydrostatic testing of cylinders and vessels, labeling, metering, safety devices, and pipework and outlet and inlet valve-connecting are thoroughly described in pamphlets issued by the association.

Standards for the design and use of air receivers are promulgated based on the ASME Boiler and Pressure Vessel Codes. The provision and use of compressed gases in indus-

trial settings must be carefully undertaken; otherwise, catastrophic situations may develop.

INDUSTRIAL HYGIENE CONTROL METHODS

Industrial hygiene control methods for reducing or eliminating environmental hazards or stressors include the following:

- ➢ Substitution of a less hazardous material for one that is harmful to health
- ➢ Change or alteration of a process to minimize worker exposure
- ➢ Isolation or enclosure of a process or work operation to reduce the number of employees exposed, or isolation or enclosure of a worker in a control booth or area
- ➢ Wet work methods to reduce generation of dust and avoid dry sweeping of dust
- ➢ Local exhaust ventilation at the point of generation or dispersion of contaminants
- ➢ General or dilution ventilation to provide circulation of fresh air without drafts or to control temperature, humidity, or radiant heat load
- ➢ Personal protective devices, such as special clothing or eye and respiratory protection
- ➢ Good housekeeping and maintenance, including cleanliness of the workplace and adequate hygiene and eating facilities
- ➢ Administrative controls, including adjusting work schedules or rotating job assignments so that no employee receives an overexposure
- ➢ Special control methods for specific hazards, such as shielding, monitoring devices, and continuous sampling with preset alarms
- ➢ Employee training and education that is specific to the hazards and includes work methods that help reduce contaminant exposure
- ➢ Emergency response training and education
- ➢ Waste treatment and disposal

A generalized diagram of these methods is shown in Figure 18–1. Each of these industrial hygiene control methods will be discussed in turn.

PRINCIPLES OF ENGINEERING CONTROLS

Substitution: Changing the Material

An often effective industrial hygiene method of control is the substitution of nontoxic or less toxic materials for highly toxic ones. However, an industrial hygienist must exercise extreme caution when substituting one chemical for another, to ensure that some previously unforeseen hazard does not occur along with the substitution. Examples of this include fire hazards, synergistic interactions between chemical exposures, or previously unknown toxicity problems attributed to the "nontoxic" substitute chemical. The classic examples of substitution as an industrial hygiene control measure include replacement of white lead in paint pigments by zinc, barium, or titanium oxides; the use of phosphorus sesequisulfide instead of white phosphorus in match-making; shotblasting instead of sandblasting; and substitution of calcium silicates and mineral wool for asbestos as an insulating material. Recently, new bismuth-containing alloys have replaced lead in the making of brass and bronze alloys. This substitution not only minimizes health concerns due to employee exposures to lead, it reduces the overall cost of OSHA and EPA compliance.

As technology advanced and more toxicity information became available, the substitutions of degreasing solvents progressed from carbon tetrachloride to chlorinated hydrocarbons such as perchloroethylene and trichloroethylene. When studies revealed the possible carcinogenicity of chlorinated solvents, these solvents were replaced with fluorinated hydrocarbons. Because the fluorinated hydrocarbon solvents have been identified as ozone depleters, hydrochlorofluorocarbons are likely interim candidates for industrial degreasing. When substituting solvents, it is always advisable to experiment on a small scale before making the new solvent part of the operation or process. Detergent-and-water cleaning solutions or a steam-cleaning process should be considered for use in place of organic solvents.

Synthetic materials rather than sandstone can be used as grinding wheels and as nonsilica parting compounds in foundry molding operations. Removing beryllium phosphors from formulations for fluorescent lamps eliminated a serious pulmonary hazard to the workers making such lamps.

A change in the physical condition of raw materials received by a facility for further processing may eliminate health hazards. Pelletized or briquette forms of materials are less dusty and can drastically reduce atmospheric dust contamination in some processes.

However, there are instances when substitution of some toxic materials may be impossible or impractical, as in the manufacture of pesticides, drugs, or solvents, and processes producing ionizing radiation.

Substituting less hazardous materials or process equipment may be the least expensive and most positive method of controlling many occupational health hazards and can often result in substantial savings. Exposure control by substitution is becoming more important from an environmental health and community air pollution perspective as well. Process materials should be selected only after review of their smog production and ozone depletion characteristics.

Substitution: Changing the Process

A change in process offers an ideal chance to concomitantly improve working conditions. Most changes are made to improve quality or reduce the cost of production. However, in some cases, a process can be modified to reduce the dispersion of dust or fume and thus markedly reduce the hazard. For example, in the automotive industry, the amount of

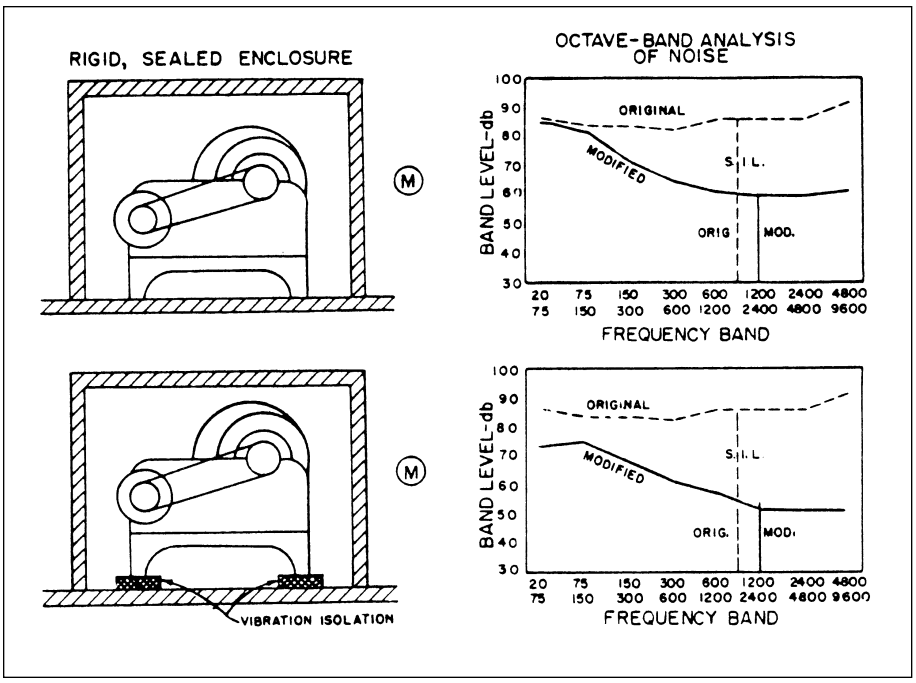


Figure 18–5. Noise can be abated by enclosing an operation (top), and adding vibration isolators reduces sound transmission even more (bottom).

lead dust created by grinding solder seams with small, high-speed rotary sanding disks was greatly reduced by changing to low-speed, oscillating-type sanders. More recently, lead solder was replaced with tin solder and silicone materials.

Brush-painting or dipping instead of spray-painting can minimize the concentration of airborne contaminants. Other examples of process changes are employing arc welding to replace riveting, using vapor degreasing in tanks with adequate ventilation controls to replace hand washing of parts in open containers, using steam cleaning of parts instead of vapor degreasing, using airless paint-spraying techniques to minimize over-spray as replacements for compressed-air spraying, and employing machine application of lead oxide to battery grids, which reduces lead exposure to operators making storage batteries.

Using automatic electrostatic paint-spraying instead of manual compressed-air paint-spraying and using mechanical continuous hopper-charging instead of manual batch-charging are additional examples of a change in process to control health hazards.

Isolation

Potentially hazardous operations should be isolated to minimize exposure to employees. The isolation can be a physical barrier, such as acoustic panels used to minimize noise transmission from a whining blower or a screaming ripsaw (Figure 18–5).

The isolation can be in terms of time, such as providing remote control semiautomatic equipment so that an operator does not have to stay near the noisy machine constantly; or the worker may be isolated or enclosed in a soundproof control booth with a clean source of air supplied to the booth.

Isolation is particularly useful for jobs requiring relatively few workers and when control by other methods is difficult or not feasible. The hazardous job can be isolated from the rest of the work operations, thus eliminating exposures for the majority of workers. Additionally, the workers actually at workstations where contaminants are released should be protected by installing ventilation systems, which probably would not be satisfactory if the workstation were not isolated (Figure 18–6).

Exposure to employees may likewise be minimized by isolating hazardous materials in place. Exposure to asbestos-containing materials and lead-based paint can be abated in some instances by sealing these materials in airtight enclosures.

It may not be feasible to enclose and exhaust all operations. Abrasive blasting operations, such as those found in shipbuilding and construction, are examples. The sandblasting should be done in a specified location, which is as far away as is practical from other employees. Another way to isolate the sandblasting is to do it when the least number of other employees would be exposed.

In some foundries, the shakeout operation may be performed during the swing shift after employees on the regular shift have gone for the day. The few shakeout workers can be provided with suitable respirators for the short time during which they are exposed to airborne dust.

Other work that can be scheduled to minimize the number of workers exposed to a hazard includes blasting in mines or quarries, which can be done at the end of or between shifts; and maintenance procedures, such as cleaning tanks and replacing filters on weekends when few workers are present. In offices, remodeling work and metal maintenance should be performed during off hours when building occupants will not be exposed to construction dust

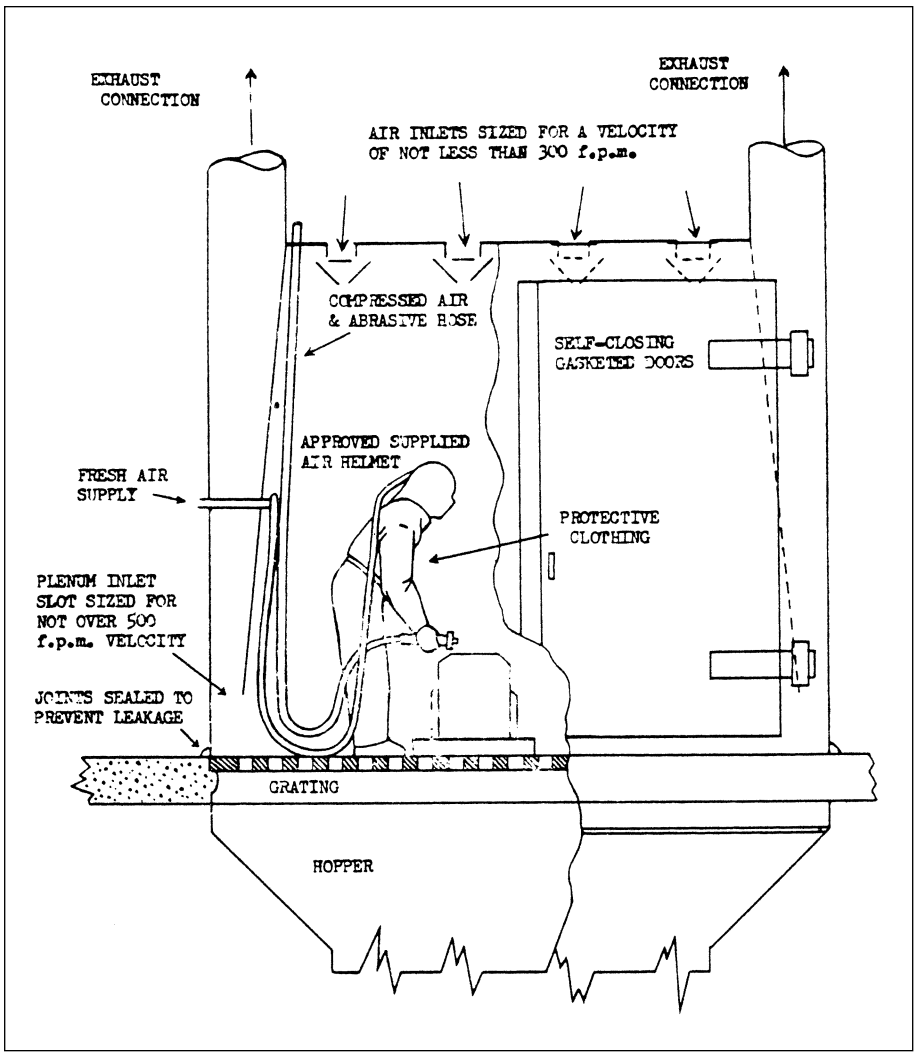


Figure 18–6. Air inlets and exhaust are arranged to sweep contaminated air away from the worker's breathing zone in this enclosed sandblast area. Downdraft averages 80 fpm over the entire floor area. Air should exhaust downward (as shown) or on two sides of the room at the floor line. (Courtesy Connecticut State Department of Health.)

and vapors from paints, adhesives, cleaning solvents, and finishes.

In some operations, other methods of control cannot be relied on to maintain contaminants at desired levels, so these operations (such as asbestos and lead remediation projects) should be isolated. Without the use of proper isolation techniques such as enclosures under negative pressure, remediation projects may generate contaminants in large quantities that disperse throughout a work area or building to expose all workers to a hazard, although only a few of them are actually engaged in the operation.

Equipment isolation can be the easiest method of preventing hazardous physical contact. Insulating a hot water line may not be economical from a strictly heat conservation standpoint but may be necessary if that line is not sufficiently isolated from people.

When very toxic materials are to be processed, automation can be used to allow handling of equipment from a remote location. Robotic techniques can reproduce many industrial procedures, thus eliminating worker exposures. The work area can be viewed by remote-control television cameras or mirrors. The degree of isolation required depends on the toxicity of the contaminant, the amount released, and work patterns around the process. Moving a process to another area is often sufficient. In other cases, a control room supplied with fresh air may be needed to isolate the process from employees monitoring the operation.

Many modern chemical facilities have centralized control rooms with automatic sampling and analysis, remote readout of various sensors, and on-line computer processing of the data and operation of the process. Some operations require complete enclosure and remote control so that nobody is exposed, as in many processes involving nuclear radiation (Figure 18–7).

Total enclosure can be accomplished by mechanization or automation to ensure that workers do not come into contact with toxic materials. The crane operators in a large foundry or in a bulk material storage building can be provided with a completely enclosed cab ventilated with filtered air under positive pressure to keep out contaminants. The same principle can be applied to heavy equipment operators in mines, coal yards, metalscrap recycling facilities, and soil remedia-

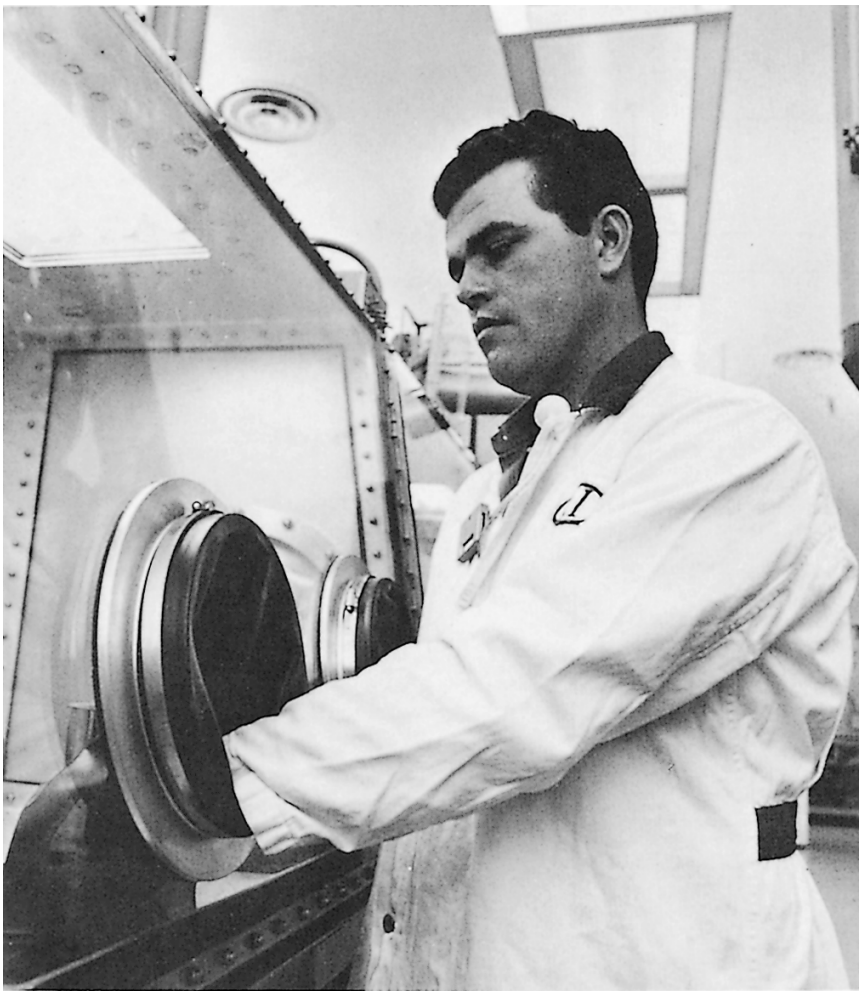


Figure 18–7. Some operations require complete enclosure. Here, a technician works with aluminum powder, used in atomic reactor fuel elements, at a glove box. He is wearing a film badge and air sampler on his lapel.

tion projects. In automatic stone-crushing, grinding, and conveying processes, only periodic or emergency attendance is required by an operator; therefore, small, well-ventilated rooms, supplied with filtered air and strategically located within a large workroom, can be occupied by the workers during the major part of the workshift.

Automated plating tanks, paint-dipping operations, and similar processes can be located in separate rooms. When continuous supervision of such operations by a worker is not necessary, general ventilation may be adequate to prevent buildup of air contamination in the workroom. If necessary, an exposed worker can be given a respirator for protection during the brief periods of exposure.

Segregating a hazardous operation or locating one or more such operations together in a separate enclosure or building not only sharply reduces the number of workers exposed but greatly simplifies the necessary control procedures.

Enclosing the process or equipment is a desirable method of control, because the enclosure prevents or minimizes the escape of contaminants into the workroom atmosphere. Enclosure should be one of the first control measures attempted, after substitution has been considered. Additional precautions must be taken when cleaning enclosed equipment or during start-up or shutdown to avoid exposure to high concentrations of the contaminant.

Enclosed equipment is usually tightly sealed and is opened only during cleaning or filling operations. Examples of such equipment include gloveboxes (Figure 18–7), airless-blast or shotblast machines for cleaning castings, and abrasive blasting cabinets.

In the chemical industry, the isolation of hazardous processes in closed systems is a widespread practice. This explains why the initial manufacture of toxic substances is often less hazardous than their subsequent use under less well-controlled conditions at other locations. In other industries, complete enclosure is often the best solution to severe dust or fume hazards, such as those from sandblasting or metal-spraying operations.

All equipment, whether enclosed or automated, requires maintenance and repair, during which control measures may have to be removed. In such circumstances, safety procedures must be specified, including confined space entry and lockout/tagout procedures (Grund, 1995), to work on such maintenance operations. These nonroutine maintenance, repair, and cleaning operations can pose the greatest expo-

sure risks to employees and should be carefully reviewed by health and safety professionals.

Isolation can also be provided by appropriate use of distance and time, for example, with respect to radiation and noise exposure. Both radiation and noise exposures decrease with an increase in the distance from the source and a decrease in the exposure time.

Ventilation

Ventilation is a method of controlling the work environment by strategically supplying (adding) or exhausting (removing) air. Ventilation is used to dilute the concentration of contaminants to acceptable levels, to remove contaminants at their source, and to heat or cool the work environment. Ventilation can also serve to control humidity, odor, and other environmental conditions for worker comfort. (See Chapters 19, Local Exhaust Ventilation of Industrial Occupancies, Chapter 20, General Ventilation of Industrial Occupancies, and Chapter 21, General Ventilation of Nonindustrial Occupancies, for more information.)

GENERAL VENTILATION

General ventilation systems supply and exhaust large volumes of air from work spaces. They are used for temperature and humidity control or to dilute the concentration of an air contaminant below hazardous levels. This system uses natural convection through open doors or windows, roof ventilators, and chimneys, or air movement produced by mechanical fans or blowers. Exhaust fans mounted in roofs, walls, or windows constitute general ventilation.

With the exception of comfort control, general ventilation should be used only in situations meeting the following criteria:

- ➢ When small quantities of air contaminants are being released into the work environment at fairly uniform rates
- ➢ When there is sufficient distance between the worker and the contaminant source to allow sufficient air movement to dilute the contaminant to safe levels
- ➢ When only contaminants of low toxicity are being used
- ➢ When there is no need to collect or filter the contaminants before the exhaust air is discharged into the community environment
- ➢ When there is no possibility of corrosion or other damage to equipment from the diluted contaminants in the work environment air

The major disadvantage of general, or dilution, ventilation is that employee exposures can be very difficult to control near the source of the contaminant where sufficient dilution has not yet occurred. For this reason local exhaust ventilation is most often the proper method to control exposure to toxic contaminants.

When air is exhausted from a work area, consideration must be given to providing makeup, or replacement, air, especially during winter months. Makeup air volumes should be equivalent to the air being removed; it should be clean and humidified and the temperature regulated as required for comfort.

Care should be taken in selecting the makeup air intake locations so that toxic gases and vapors from discharge stacks, emergency vents, or operations outside of the building that generate hazardous contaminants are not brought back into work areas. When exhaust stacks and air supply inlets are not separated adequately, the exhaust air may be directed into the air inlet and recirculated to work areas. Inadvertent recirculation of exhaust air contaminants is a common problem, which ideally should be addressed in the design phase. It is not uncommon to find the air supply intake for a facility located adjacent to a loading dock or alley where gasoline and diesel engine vehicles idle. This can result in contamination of the "fresh" air supply and will almost certainly cause exposure or odor problems, or both.

Because equipment for moving, filtering, and tempering air is expensive, some engineers attempt to save money by recirculating some exhaust air into the supply system. Adequate monitoring of the recirculated air is necessary to prevent buildup of harmful contaminants. Recirculation of exhaust air may be forbidden in certain locations, such as smoking lounges. Check state and federal regulations and American Socierty of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards.

Design of the general ventilation system in a nonindustrial or office environment must take into account conditions that affect worker comfort, such as temperature and humidity, odor level, the space provided per occupant, and concentrations of tobacco smoke. Construction practices, construction materials, and heightened public awareness have made indoor air quality an important ventilation design issue. ASHRAE Consensus Standard 62–1999 should be referred to for design parameters. (See Chapter 21, General Ventilation of Nonindustrial Occupancies.)

General ventilation should not be used where there are major localized sources of air contamination (especially highly toxic dusts and fumes); local exhaust ventilation is more effective and economical in such cases. More information on general ventilation is presented in Chapter 20, General Ventilation of Industrial Occupancies.

LOCAL EXHAUST VENTILATION

Local exhaust ventilation is considered the classic method of control. Local exhaust systems capture or contain contaminants at their source before they escape into the work area environment. A typical system consists of one or more hoods, ducts, an air cleaner if needed, and a fan (Figure 18–8).

Local exhaust systems remove air contaminants rather than just dilute them, but removal of the contaminant is not always 100 percent effective. This method should be used when the contaminant cannot be controlled by substitution, changing the process, isolation, or enclosure. Although a

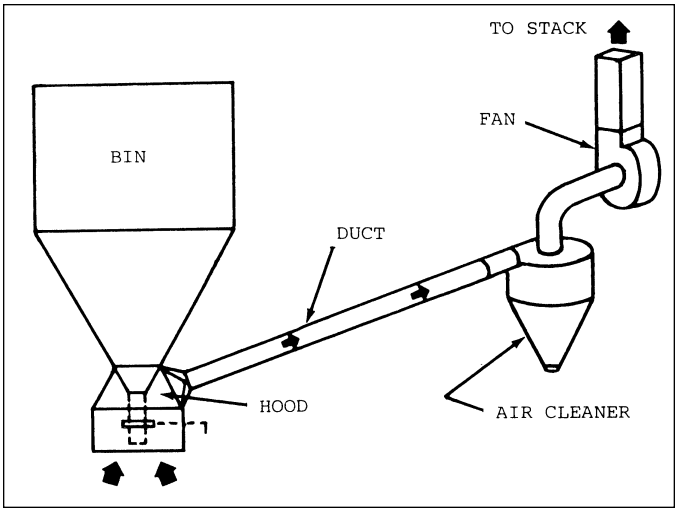


Figure 18–8. A typical local exhaust ventilation system consists of hoods, ducts, air cleaner, fan, and stack. (Courtesy American Conference of Governmental Industrial Hygienists.)

process has been isolated, it still may require a local exhaust system.

A major advantage of local exhaust ventilation systems is that they require less airflow than dilution ventilation systems. The total airflow is important for plants that are heated or cooled, because heating and air-conditioning costs are a significant operating expense. Also, local exhaust systems can be used to conserve or reclaim reusable materials.

Two main principles govern the proper use of local exhaust ventilation to control airborne hazards. First, the process or equipment is enclosed as much as possible; and second, air is withdrawn at a rate sufficient to ensure that the direction of airflow is into the hood and that the airflow rate will entrain the contaminant into the airstream and thus draw it into the hood (Figure 18–9).

The proper design of exhaust ventilation systems depends on many factors, such as the temperature of the process, the physical state of the contaminant (dust, fume, smoke, mist, gas, or vapor), the manner in which it is generated, the velocity and direction with which it is released to the atmosphere, and its toxicity (Figure 18–10).

Local exhaust systems can be difficult to design. The hoods or pickup points must be properly shaped and located to capture air contaminants, and the fan and ducts must be designed to draw the correct amount of air through each hood. Hood selection is based on the characteristics of the contaminants and how they are dispersed. The hood should be located so that the contaminant is moved away from the operator's breathing zone. The use and selection of an air cleaner are dependent on the contaminant, its concentration, and air pollution standards. (See Chapter 19, Local Exhaust Ventilation of Industrial Occupancies, for more details).

The low-volume, high-velocity exhaust system uses small volumes of air at relatively high velocities to control dust. Control is achieved by exhausting the air directly at the point of dust generation using close-fitting hoods. Capture velocities are rel-

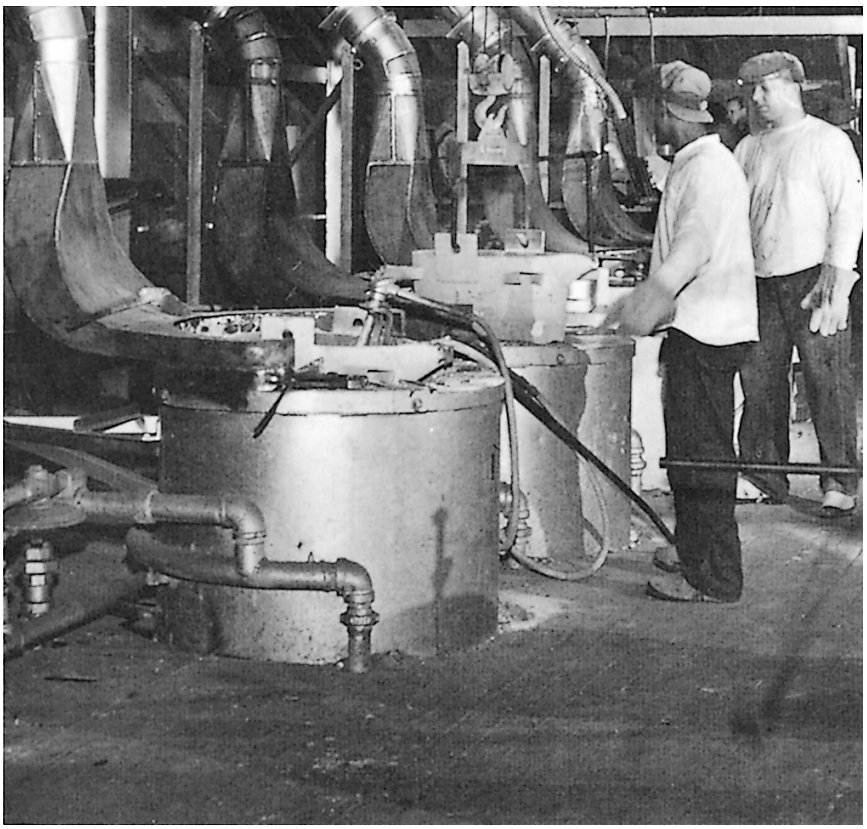


Figure 18–9. The fumes arising from lead-melting operations are controlled by local lateral-slot exhaust ventilation. (Courtesy Ford Motor Co.)

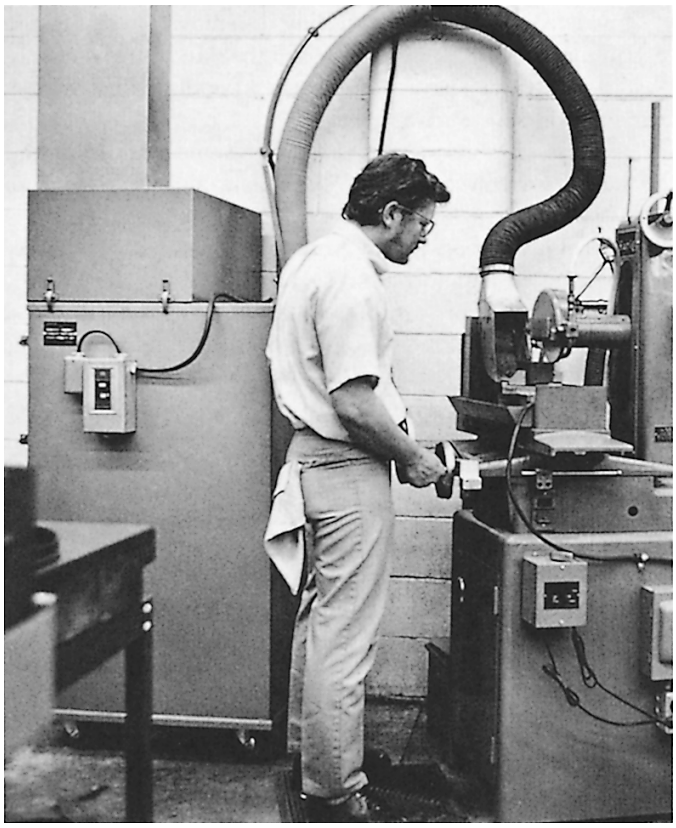


Figure 18–10. A typical local exhaust ventilation system-a dust collector-traps contaminants near their source, so the worker is not exposed to harmful concentrations.

atively high, but the exhaust volume is low. For flexibility, small-diameter, lightweight plastic hoses are used with portable tools, resulting in very high duct velocities. This method allows the application of local exhaust ventilation to portable tools, which otherwise require relatively large air volumes and large ductwork when controlled by conventional exhaust methods.

Portable local exhaust ventilation systems can be useful for facilities where dust- or fume-generating operations are not stationary. These machines capture contaminated air, filter particulate matter, and exhaust cleaned air into the work area. They can be a cost-effective solution for welding stations and enclosed areas where renovation and construction are being performed.

After the local exhaust ventilation system is installed and set in operation, its performance should be checked to see that it meets the engineering specifications—correct rates of airflow and duct velocities. Its performance should be rechecked periodically as a maintenance measure.

Full details on the design and operation of local exhaust ventilation systems are given in Chapter 19, Local Exhaust Ventilation of Industrial Occupancies.

ADMINISTRATIVE CONTROLS

Engineering controls are to be used as the first line of defense against workplace hazards. Some circumstances require administrative controls, such as in cases when engineering controls are not technologically feasible, or during the installation of engineering controls. Administrative control of occupational hazards, such as work period reduction, job rotation, appropriate work practices, proper maintenance, and personal hygiene, depends on constant employee implementation or intervention, which makes them a less desirable form of control.

However, administrative controls are often useful in supplementing engineering controls to achieve acceptable exposure levels. The majority of the major OSHA health standards require administrative control measures including hygienic change rooms, regulated areas, and specific work and hygiene practices.

Reduction of Work Periods

Reduction of work periods is another method of control in limited areas where engineering control methods at the source are not practical. Heat stress can be managed by following a work-rest regimen that prevents excessive fatigue and reduces heart rate. For example, in the job forge, foundry, and construction industries, especially in hot weather, frequent rest periods are used to minimize the effects of exposures to high temperatures, thereby lessening the danger of heat exhaustion or heatstroke.

For workers who must labor in a compressed-air environment, schedules of maximum length of workshift and length of decompression time have been prepared. The higher the pressure, the shorter is the workshift and the longer the decompression time period.

However, job rotation, when used as a way to reduce employee exposure to toxic chemicals or harmful physical agents, must be used with care. Rotation, although it may keep exposure below recommended limits, exposes more workers to the hazard.

Wet Methods

Airborne dust hazards can often be minimized or greatly reduced by applying water or other suitable liquid. Wetting of floors before sweeping to keep down the dispersion of harmful dust is advisable when better methods, such as vacuum cleaning, cannot be used.

Wetting down is one of the simplest methods of dust control. Its effectiveness, however, depends on proper wetting of the dust. This may require the addition of a wetting agent (surfactant) to the water and proper disposal of the wetted dust before it dries out and is redispersed.

Significant reductions in airborne dust concentrations have been achieved by the use of water forced through the drill bits used in rock drilling operations. Many foundries successfully use water under high pressure for cleaning castings in place of sandblasting. Airborne dust concentrations can be kept down if molding sand is kept moist, molds with cooled castings can be moistened before shakeout, and the floors are wetted intermittently.

High-pressure water washing, used in a contained space or enclosure and with proper work practices, can effectively reduce airborne dusts and asbestos in the demolition and construction industry. In some instances it may be necessary to blanket the dust source completely. The particles must be thoroughly wetted by means of high-pressure sprays, wetting agents, deluge sprays, or other procedures while in the containment.

Batch charging of materials that are slightly moistened or that are packaged in paper bags rather than in a dry bulk state may eliminate or reduce the need for dust control in storage bins and batch mixers.

Personal Hygiene

Personal hygiene is an important control measure. The worker should be able to wash exposed skin promptly to remove accidental splashes of toxic or irritant materials. If workers are to minimize contact with harmful chemical agents, they must have easy access to hand-washing facilities (Figure 18–11).

Inconveniently located washbasins invite such undesirable practices as washing at workstations with solvents, mineral oils, or industrial detergents, none of which is appropriate or intended for skin cleansing.

Many workplace hand cleansers are available as plain soap powders, abrasive soap powders, abrasive soap cakes, liquids, cream soaps, and waterless hand cleaners (Figure 18–12).

Powdered soaps provide a feeling of removing soils because of stimulation of the nerve endings in the skin by the abrasives. Waterless cleaners have become very popular because they remove most soils, such as greases, grimes, tars, and paint, with relative ease. Be aware, however, that some waterless hand cleaners have solvent bases. Soaps may also contribute to industrial dermatitis. Sensitive persons may require pH-neutral soaps or moisturizing agents. Antibacterial soaps are necessary in workplaces where infectious agents may be present.

The provision of washing facilities, emergency showers, and eyewash fountains is required in areas where hazardous or extremely toxic materials are handled. These should be located in an area convenient to employee workstations in case of accidental exposures. The common practice of removing particulates from clothing or disposable coveralls using compressed air should be forbidden. This practice causes the material to become airborne and increases the risk of employee exposure.

When designated or suspected carcinogens are involved, stringent regulation of work areas and activities must be undertaken. The OSHA carcinogen regulations state that the employer must set aside a regulated area where only the particular carcinogen may be produced or handled. Only authorized and specially trained personnel with proper personal protection may be allowed to enter that area.

The eating, storage, or drinking of foods and liquids in areas where toxic materials are used should be forbidden.

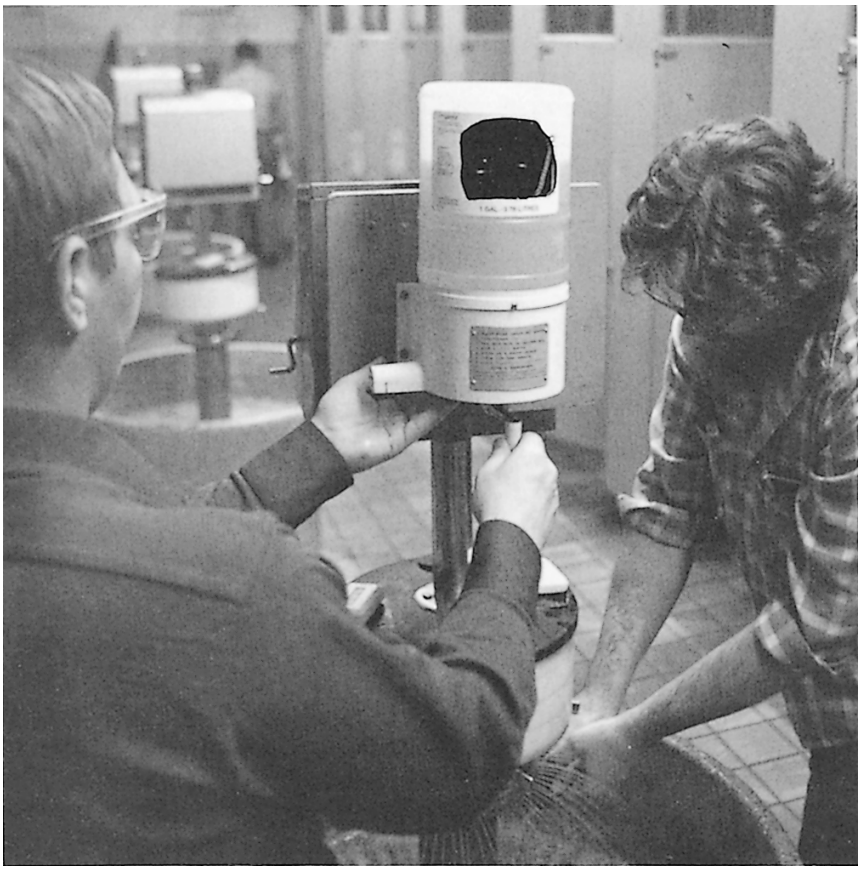


Figure 18–11. To minimize worker contact with harmful chemical agents, hand-washing facilities must be conveniently located.

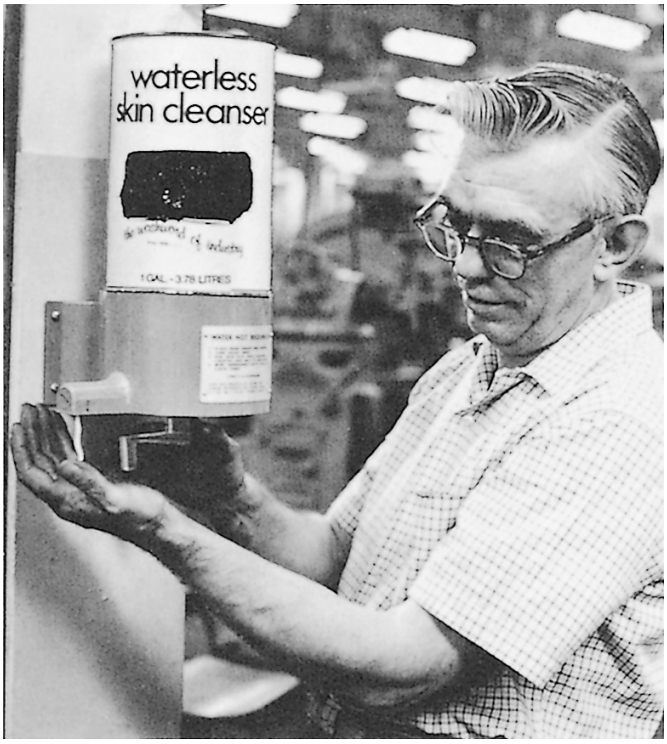


Figure 18–12. Industrial hand cleansers are available as plain soap powders, abrasive soap cakes, liquids, cream soaps, and waterless hand cleaners.

All entrances to the regulated area where biohazards or suspected carcinogens are handled must be properly posted to inform employees of hazards and regular and emergency procedures required. Set aside special areas for employees to change clothing and protective equipment.

Many of the major OSHA health standards, such as asbestos, lead, and coke oven emissions, require hygienic change rooms and showers.

Housekeeping and Maintenance

Good housekeeping plays a key role in the control of occupational health hazards. Good housekeeping is always important, but where there are toxic materials, it is of paramount importance, and often mandated by OSHA regulation. Remove dust on overhead ledges and on the floor before it can become airborne by traffic, vibration, and random air currents.

Immediate cleanup of any spills of toxic materials is a very important control measure. A regular cleanup schedule using vacuum cleaners is an effective method of removing dirt and dust from the work area. Never use compressed air to remove dust from rafters and ledges.

Good housekeeping is essential where solvents are stored, handled, and used. Immediately remedy leaking containers or spigots by transferring the solvent to sound containers or by repairing the spigots. Clean up spills promptly. Deposit all solvent-soaked rags or absorbents in airtight metal receptacles and remove daily to a safe location for proper disposal.

Maintenance Provisions

If the thermostat on a vapor degreaser fails or is accidentally broken, excessive concentrations of trichloroethylene might quickly build up in the work area unless the equipment is shut down immediately and the necessary repairs made. Abnormal operating conditions can be detected by continuously monitoring airborne contaminants with instrumentation that triggers an alarm when concentrations exceed an established level. The workers or supervisors can then take steps to reduce airborne levels.

A key objective should be to provide for periodic shutdown of equipment for maintenance. Provisions should be made for cleaning the equipment and piping systems by flushing them with water, steam, or a neutralizing agent (depending on the conditions involved) to render them nonhazardous before dismantling. Safety considerations, such as the control of hazardous energy (lockout/tagout) and confined space entry, should be evaluated prior to conducting the maintenance work.

Before any equipment is disassembled, it is essential that it be checked for the presence of toxic or hazardous materials. In cases in which this is not possible, employees involved in the disassembling operation should wear proper protective clothing and respirators, if needed. Contaminated equipment, tools, and protective clothing must be decontaminated before they are removed from the work area.

Operations and maintenance programs for hazardous materials or agents such as lead, asbestos, bioaerosols, and noise are important tools in the prevention of employee exposures. These programs are designed to identify and control hazardous conditions by means of periodic inspection, contaminant monitoring, and hazard abatement.

SPECIAL CONTROL METHODS

Many of the general methods mentioned previously (either alone or in combination) can be used for the control of most occupational health hazards. A few special methods, however, deserve particular mention.

Shielding

This is one of the better control measures used to reduce or eliminate exposures to physical stresses such as heat, and ionizing, and nonionizing radiation. Lead and concrete are two materials commonly used to shield employees from high-energy ionizing radiation sources, such as particle generators and radioisotopes. Specialized shielding can also be used for protection from electric and magnetic fields (see Chapter 11, Nonionizing Radiation).

Shielding can also be used to protect employees against exposure to radiant heat sources. Furnaces can be shielded with shiny reflective aluminum panels. Nonreflective metal is not effective because it may act as a "black body," which absorbs and then reradiates the heat.

WASTE DISPOSAL

Industrial hygiene controls include the proper disposal of wastes. Management and disposal of hazardous waste is regulated by the complex requirements of several governmental agencies (see Chapter 28, Government Regulations). To develop an appropriate waste management plan, employers must first make the following determinations:

- ➢ Are potentially regulated waste materials generated at this site?
- ➢ Are the wastes hazardous, special, infectious, or radioactive by regulatory definition? Have they been tested to determine hazardous characteristics?
- ➢ Can wastes be treated and rendered innocuous prior to disposal?
- ➢ Can wastes be recycled as part of the process?
- ➢ Given the quantities of waste generated, is the company a small-quantity or large-quantity generator?
- ➢ Is the company a waste generator, transporter, or treatment/storage/disposal facility?

These determinations will provide much of the information necessary to choose treatment and disposal alternatives. These decisions are particularly onerous, as generators of hazardous waste are perpetually responsible for on-site and off-site damages to the environment and worker and community health. This is often referred to as cradle-to-grave responsibility.

Disposal of hazardous materials must be done by highly trained individuals under strict supervision. Procedures should be established in accordance with the EPA's Resource Conservation and Recovery Act (RCRA) and other applicable regulations for the safe disposal of hazardous chemicals, toxic residues, and other contaminated waste, as well as containers of chemicals that are no longer needed and containers whose labels have been lost or obliterated.

A competent chemist can determine the best way to neutralize or detoxify small amounts of chemicals that are no longer needed. In some instances it may be appropriate to perform experimental investigations to determine a means of neutralizing and rendering waste products harmless before full-scale disposal operations are begun. There are a number of methods by which some dangerous chemicals can be rendered safe for disposal.

A number of facilities are available for off-site disposal of hazardous materials. All of them can be expensive and none of them provides a universal means of disposal for all hazardous materials. Landfills, incinerators, and chemical treatment facilities are the most commonly used disposal options for hazardous waste. Before a disposal facility is chosen, a determination should be made that the facility is competently managed, is in regulatory compliance, and has significant financial resources.

PERSONAL PROTECTIVE EQUIPMENT

When it is not feasible to render the work environment free of occupational health hazards, it may be necessary to protect the worker from the environment with personal protective equipment. The use of personal protective equipment should be considered a last resort, when engineering or administrative controls are not possible or when they are not sufficient to achieve acceptable limits of exposure. Personal protective equipment may be appropriate during short exposures to hazardous contaminants, such as during nonroutine equipment maintenance or emergency responses to spills. The primary disadvantage of personal protective devices is that they do not eliminate the hazard from the workplace, and thus their failure results in immediate exposure to the hazard. A protective device may become ineffective without the wearer's knowledge, resulting in serious harm. The integrity and fit of a personal protective device is vital to its effectiveness.

The Occupational Safety and Health Administration (OSHA) requires that employers perform a workplace hazard assessment to determine if the use of personal protective equipment is warranted and to determine the proper selection of protective devices (29 *CFR* 1910.132). Successful use of any personal protective equipment requires that a program be established and administered. The purpose of the program is to ensure that personal protective equipment is properly chosen, used, and maintained to protect workers. Employee training and record keeping as required by regulation must be part of this program.

Respiratory Protective Devices

Respiratory protective devices are normally restricted for use in intermittent exposures or for operations that are not feasible to control by other methods. Respiratory protection should not be considered a substitute for engineering control methods.

Respiratory protection devices offer emergency or short-term protection. Respirators are a primary protective device for normal operations only when no other method of control is possible (Figure 18–13).

Respirators should be used when it is necessary to enter a highly contaminated atmosphere for rescue or emergency repair work; as a means of escape from a suddenly highly contaminated atmosphere; for short-term maintenance or repair of equipment located in a contaminated atmosphere; and for normal operation in conjunction with other control measures when the containment is so toxic that other control measures, such as ventilation, cannot be relied upon safely.

An approved respirator must be selected for the particular hazard and environment in which it is to be used (Figure 18–14).

The type of air contaminant, its expected maximum concentration, the possibility of oxygen deficiency, the useful life of the respirator, the escape routes available, and other factors must all be considered in selecting the proper type of respirator for emergency use or for standby purposes. When these factors are not known with certainty, the device providing the greatest factor of safety must be used.

Figure 18–13. This operator is provided with clean, respirable air.

There are two general types of respiratory protective devices: air-purified respirators, which remove the contaminant from the breathing air by filtering or chemical absorption, and air-supplied respirators, which provide clean air from an outside source or from a tank. Full details of types of respirators certified by the National Institute of Occupational Safety and Health (NIOSH) should be obtained from the manufacturer. Only NIOSH-certified respirators should be used (42 *CFR* 84). (See Chapter 22, Respiratory Protection, for more details.)

Half-mask cartridge respirators cover the mouth and nose. Full-facepiece respirators also protect the eyes. For dust protection, there are a large number of respirators that have met the requirements established by NIOSH, which call for high filtering efficiency and low resistance to breathing. Respirators have been certified for protection against metal fumes, mists, and pesticide application.

Air-line respirators may be preferred by workers to chemical cartridge or mechanical filter respirators because they are cooler and offer no resistance to breathing; however, they require a proper source of Grade D breathing air (ANSI/Compressed Gas Association Commodity Specification for Air, G–7.1–1989) and a suitable compressor located outside of the contaminated atmosphere.

Self-contained breathing apparatuses, which are mostly used for emergency and rescue work, have face masks attached by hoses to compressed air cylinders. Such apparatuses enable a worker to enter a contaminated or oxygen-deficient atmosphere, up to certain limits specified in the respirator certifications.

Selection of the proper type of respiratory protective equipment should be based on the following factors:

- ➢ Identification of the substance or substances for which respiratory protection is necessary and the activities of the workers
- ➢ Determination of the hazards of each substance and its significant physical and chemical properties, particularly the presence or absence of oil particles
- ➢ Determination of the maximum levels of air contamination expected, probability of oxygen deficiency, and the condition of exposure
- ➢ Determination of the period of time for which respiratory protection must be worn
- ➢ Determination of the capabilities, physical characteristics, and limitations essential to the safe use of the respiratory protective device
- ➢ Identification of facilities needed for maintenance
- ➢ Determination of the location of the hazardous work area in relation to the nearest area with respirable-quality air
- ➢ Occupational exposure limit for substance
- ➢ Respirator assigned protection factors

Because wearing a respirator often becomes uncomfortable after extended periods, the worker must fully realize the need for protection or he or she will not wear it. To

Figure 18–14. An approved respirator must be selected for the particular hazard and environment.

obtain the worker's cooperation, the following factors are important:

- ➢ Prescribe respiratory protective equipment only after every effort has been made to eliminate the hazard.
- ➢ Explain the situation fully to the worker.
- ➢ Instruct the worker in the proper use and limitations of the respirator.
- ➢ Fit the respirator carefully according to OSHA guidelines.
- ➢ Provide for maintenance and cleanliness, including sterilization before reissue.

A respirator program is required by OSHA whenever respirators are used. The OSHA requirements for a respiratory protection program are contained in the *Code of Federal Regulations for General Industry* at 29 *CFR* 1910.134. Certain OSHA standards (such as asbestos and lead standards) have other specific regulations on respirator use. Check the *Code of Federal Regulations* for this information. (See Chapter 22, Respiratory Protection, for more details.)

Protective Clothing

Chemical-protective clothing is worn as a barrier to a chemical, physical, or biological hazard that may cause injury if it contacts or is absorbed by the skin. Applications of chemical protective clothing include the following:

- ➢ Emergency response
- ➢ Hazardous waste site cleanup and disposal
- ➢ Asbestos removal
- ➢ Agricultural application of pesticides

A broad range of chemical-protective clothing is available to protect the body. Gloves, gauntlets, boots, aprons, and coveralls are available in a number of materials, each designed for protection against specific hazards. Choosing the most appropriate chemical-protective clothing depends on the hazards present and the tasks to be performed. Protective clothing is manufactured from different materials that protect against acids, alkalis, solvents, oils, and other chemical and physical agents. The selection should take into account the performance of the protective clothing in exposure reduction, the physical limitations created by using protective clothing, and site-specific factors. Physical and psychological stress, impaired mobility and vision, and heat stress influence or limit the selection of protective clothing.

The factors that should influence selection of protective clothing are as follows:

- ➢ Clothing design
- ➢ Material chemical resistance
- ➢ Physical properties
- ➢ Ease of decontamination
- ➢ Cost
- ➢ Chemical-protective clothing standards

Chemical-protective clothing is manufactured in a variety of styles and configurations to protect specific parts of the body or the entire body. Selection of the proper equipment should include design considerations such as clothing configuration and construction, sizes, ease of putting on and taking off, accommodation of other selected ensemble equipment, comfort, and restriction of mobility.

The effectiveness of protective clothing against chemical exposure depends on how well the material resists permeation, degradation, and penetration. Permeation is the process by which a chemical moves through a protective clothing material on a molecular level. Degradation occurs when chemical contact causes deterioration of the physical properties of the protective clothing material and causes, for example, discoloration, swelling, or loss of physical strength. Penetration is the direct flow of a chemical through closures, seams, pinholes, or other imperfections in the protective clothing material.

No material protects against all chemicals and combinations of chemicals, and no material currently available is an effective barrier to prolonged chemical contact. Protective clothing material recommendations for chemicals based on an evaluation of chemical resistance test data is available in *Quick Selection Guide to Chemical Protective Clothing* (Mansdorf, 1997) and from vendors. Many vendors and manufacturers supply charts with permeation and degradation test data and material recommendations. Protective garments constructed of rubber, neoprene, nitrile, polyvinyl chloride, and other synthetic fibers and coatings are available. It is important to select the material that protects most effectively against the specific hazard in question (acids, alkalis,

oils, fibers, etc.). For mixtures of chemicals, materials having the broadest chemical resistance should be worn.

Chemical-protective materials offer wide ranges of physical qualities in terms of strength, resistance to physical hazards, and operation/effectiveness in extreme environmental conditions. The following parameters should be considered: physical strength; tear, puncture, cut, and abrasion resistance; flexibility to perform needed tasks; flame resistance; and integrity and flexibility under hot and cold extremes.

The difficulty involved in decontaminating protective clothing and the endurance of the material may dictate whether disposable or reusable clothing is selected. The relative cost of replacement and decontamination depend on the garment and the hazard. Limited-use/disposable chemical-protective clothing can be provided to minimize employee exposure to hazardous chemicals and at a reasonable cost. These types of garments are not designed to provide high levels of protection and should be used appropriately.

Body protection clothing, ranging from aprons to limited-use/disposable coveralls to totally encapsulating chemical-protective suits, are constructed of a flexible plastic or rubber film, sheet, coated plastic, or laminate. In contrast, totally encapsulating chemical-protective suits (TECP) are designed to prevent chemical exposure to the wearer.

For intermittent protection against radiant heat, reflective aluminum clothing is available. These garments need special care to preserve their essential shiny surface. Air-cooled jackets and suits are available to minimize the risk of heat-related illnesses. For protection against ionizing radiation, garments constructed of lead-bearing materials are available.

OSHA requires that employers provide, and require employees to use, appropriate hand protection when there is a risk of absorption of harmful substances; chemical or thermal burns; extreme temperatures; or severe cuts, lacerations, abrasions, or punctures (29 *CFR* 1910.138).

Gloves are the most common form of chemical-protective clothing. Gloves should be selected for a specific job according to the guidelines above. Manufacturers provide a large selection of gloves made of butyl rubber, natural rubber, neoprene, nitrile rubber, polyvinyl alcohol, polyvinyl chloride, Teflon, Viton, and other construction materials. The material that has the highest level of protection should be used. A thicker glove will increase the level of protection but will result in loss of dexterity. Impregnated gloves protect against cuts and abrasions but are not liquid-proof, and they are therefore not chemical resistant. Cotton or leather gloves are useful for protecting the hands against friction and dust.

More information on the subject of protection against skin hazards and the use of barrier creams is presented in Chapter 3, The Skin and Occupational Dermatoses. Also consult applicable OSHA regulations and ANSI standards.

Eye and Face Protection

Eye and face protection includes safety glasses, chemical goggles, and face shields. The correct type of protector is chosen based on the hazard (such as corrosive liquids and vapors, foreign bodies, or ultraviolet radiation). Goggles fit snugly to the face, preventing chemical exposure in the event of a splash, and, depending on the style, may prohibit vapor exposure. Face shields are designed only to prevent direct splash exposures to the face and not to provide complete eye protection. Eye protection from exposure to ultraviolet radiation, such as that produced in welding operations, is accomplished with filter lenses of the correct shade mounted in the welding helmet.

Many chemicals in the workplace can cause significant eye damage and facial scarring from direct chemical contact. It is important that the protective device be worn at all times when the hazard is present. (Refer to Chapter 5, The Eyes, for further information. Also consult applicable OSHA regulations and ANSI standards.)

Hearing Protection

Personal hearing protectors, such as earplugs or earmuffs, can provide adequate protection against noise-induced hearing impairment. The wearer is afforded effective protection only if the hearing protectors are properly selected, fitted, and worn. Like other types of personal protective equipment, these devices should be used as an exposure control alternative when noise exposures cannot feasibly be reduced below the OSHA permissible limit. When the noise level is 85 dBA or higher and the employee has suffered a significant threshold shift, hearing protection must be used.

There are primarily two forms of hearing protectors: insert types, which seal against the ear canal walls, and earmuffs, which seal against the head around the ear. Choice of the proper hearing protection should take into account the physiological and anatomical characteristics of the wearer, the noise exposure dose, the work activity, and environmental conditions (for example, dusty atmosphere). Refer to Chapter 9, Industrial Noise, for more information on hearing conservation.

EDUCATION AND TRAINING

Proper training and education are critical to supplement engineering controls and ensure the success of exposure controls in the workplace. It is important that all employees be provided the health and safety information and instruction needed to minimize their occupational health risk and that of their coworkers.

In a typical manufacturing plant, the primary responsibility for safe operation and control rests with the line organization of the operations department. This generally would include a first-line supervisor, a shift supervisor, and a facility area manager, all people familiar with every aspect of the day-to-day operation of the facility and the manufacturing process and readily available when critical decisions must be made.

The education of supervisors usually is process and equipment oriented. The aim of the safety and health professional

should be to teach them about the safety and health hazards that may be found in their work areas. The supervisors should be told when and under what circumstances to request aid in solving the problems those hazards pose. Supervisors should be knowledgeable and well informed about hazardous processes, operations, and materials for which they are responsible.

Short courses on industrial hygiene can be an easy way to transmit a lot of valuable information with a small expenditure of time. Industrial hygiene short courses for managers should identify health hazards in broad areas. The courses should also consider the cost-benefit relationships of controlling health hazards in the work environment.

The worker must know the proper operating procedures that make engineering controls effective. If the worker performs an operation away from an exhaust hood, the purpose of the control measure will be defeated and the work area may become contaminated. Workers can be alerted to safe operating procedures through booklets, instruction signs, labels, safety meetings, and other educational devices.

The safety and health professional, by persuading a worker to position the exhaust hood properly or to change the manner of weighing a toxic material or of handling a scoop or shovel, can do much to minimize unnecessary exposure to air contaminants. For normal facility operations, a prescribed health hazard evaluation routine should be set up. This should include monitoring the exposures of the personnel involved. It can be accomplished by keeping a record of the exposures to chemical and physical agents in work areas.

In addition to the normal operating instructions that each employee is given when starting a new job, employees assigned to areas where exposures to toxic chemicals can occur must, by law, be given a special indoctrination program.

Also be sure to give employees training in how to respond to emergencies. Information on when *not* to respond is also critical. Many deaths have occurred when untrained workers rushed in to save fallen co-workers and were overcome themselves.

In order to minimize operator error, employees should be supplied with a detailed instruction manual outlining procedures for all foreseeable situations.

Health hazards affect the workers who are exposed and work directly with materials, process equipment, and processes. These employees should know about the effects of exposure to the materials and energies they work with so that controls can be installed before those problems become severe. A properly informed worker can often anticipate and take steps to control health hazards before they become serious. Once the hazard is known, the supervisor or facility engineers can issue work orders to eliminate the problem.

Workers should be given reasons for wearing respirators, protective clothing, and goggles. They also should be informed of the necessity of good housekeeping and maintenance. Because new materials are constantly being marketed and new processes being developed, reeducation and follow-up instruction must also be part of an effective industrial hygiene control program.

Over 100 specific OSHA standards contain training requirements. Some of these standards make it the employer's responsibility to limit certain job assignments to employees who have had special training that defines them as certified, competent, or qualified with respect to a particular hazard.

OSHA has developed Voluntary Training Guidelines to assist employers in determining training needs as well as developing and conducting the training. OSHA encourages employers to follow the model provided in the Voluntary Training Guidelines. The model can be used to develop training programs for a variety of hazards and to assist in compliance with training requirements in specific standards. The guidelines are as follows:

- ➢ Determine whether training is needed.
- ➢ Identify training needs.
- ➢ Identify goals and objectives.
- ➢ Develop learning activities.
- ➢ Conduct the training.
- ➢ Evaluate program effectiveness.
- ➢ Improve the program effectiveness.

Specific training requirements are set forth by OSHA for general industry in the Hazard Communication, Process Safety Management, Asbestos, Lead, and Bloodborne Pathogens Standards, among others. For example, the Hazard Communication Standard requires a training program that covers the following types of information:

- ➢ Requirements of the standard
- ➢ Identification of operations in the workplace where hazardous materials are present
- ➢ Methods and observations used to detect the presence of hazardous materials in the work area
- ➢ Physical and health hazards of those materials
- ➢ Hazards associated with chemicals in unlabeled pipes
- ➢ Hazards of nonroutine tasks
- ➢ Measures that employees can take to protect themselves from these hazards
- ➢ Explanation of the hazardous materials labeling system
- ➢ Explanation of Material Safety Data Sheets (MSDSs)
- ➢ Details on the availability and locations of Hazardous Material Inventory, MSDSs, and other printed Hazard Communication Program materials

There are also training requirements in the OSHA construction industry standards such as occupational health and environmental controls, personal protective and life-saving equipment, among others.

The future of state and federal training requirements, led by California's Illness and Injury Prevention Act (Senate Bill 198), focuses on preventing rather than reacting to hazards. Under California's regulation, employers must identify the person responsible for implementing a Written Injury and Illness Prevention Program and provide training in health

and safety matters to all employees. This approach is intended to improve efforts to prevent workplace hazards by identifying and evaluating hazards during periodic scheduled inspections.

HEALTH SURVEILLANCE

Health surveillance, although not an occupational exposure control, can be used to prevent health impairments by means of periodic evaluations. A health surveillance program includes preplacement, periodic, special purpose, and hazard-oriented examinations.

Medical surveillance is mandated by specific OSHA, MSHA, and Environmental Protection Agency (EPA) regulations. Over 30 OSHA standards and proposed standards contain medical surveillance requirements. Among these are the asbestos, lead, formaldehyde, and hazardous waste operations standards.

Hazard-oriented medical surveillance monitors biological indicators of absorption of chemical agents based on analysis of the agent or its metabolite in blood, urine, or expired air. Inorganic lead absorption is measured by blood lead levels, and carbon monoxide absorption is indicated by carboxyhemoglobin levels in blood or carbon monoxide in exhaled air. Refer to Chapter 25, The Occupational Medicine Physician, for a complete discussion of health surveillance.

SUMMARY

Control of occupational exposures to injurious materials or conditions may be accomplished by means of one or more of the following methods:

- ➢ Proper design engineering
- ➢ Substitution of less toxic materials or changes or process
- ➢ Isolation or enclosure of the source or the employee
- ➢ Local exhaust ventilation at the point of generation or dissemination of the air contaminant
- ➢ General ventilation or dilution with uncontaminated air
- ➢ Maintenance and housekeeping
- ➢ Personal protective equipment
- ➢ Employee information and training
- ➢ Proper waste disposal practices

One or a combination of these methods may be necessary to prevent excessive exposures to hazardous materials or physical agents.

Education of workers and periodic workplace inspections are paramount in the prevention of injury and illness. If engineering and administrative controls and the use of personal protective equipment are to be effective in minimizing occupational health risk, workers must be properly trained.

Management is responsible for furnishing the facilities and products required to keep the workplace healthful and safe. The worker also has responsibilities in a health hazard control program, including the following: to wear protective equipment if it is required, to use the local exhaust ventilation system properly, and to observe all company rules relating to cleanup and disposal of harmful materials.

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Chapter 19

Local Exhaust Ventilation

revised by Henry J. McDermott, CIH, PE

This chapter describes the following aspects of local exhaust ventilation (LEV) *systems: typical components, principles of operation, methods to evaluate performance, and ways to resolve problems. It is designed to give safety and industrial hygiene practitioners sufficient knowledge to determine where LEV is needed, participate with engineers and others during system design, and evaluate and troubleshoot existing systems.*

LEV systems are covered in this chapter while dilution ventilation is described in Chapter 20. The Bibliography for both chapters appears at the end of Chapter 20, Dilution Ventilation for Industrial Workplaces.

INTRODUCTION

Ventilation is an important method for reducing employee exposures to airborne contaminants. However, ventilation is only one way to reduce exposures and may not be as economical or effective as other control techniques, such as reducing emissions into the work area by sealing equipment to prevent contaminant release or substituting less toxic or volatile chemicals.

There are two major types of industrial ventilation:

- *Dilution systems* reduce the concentration of contaminants released into the workroom by mixing with air flowing through the room. Either natural or mechanically induced air movement can be used to dilute contaminants.
- *Local exhaust ventilation (LEV) systems* capture or contain contaminants at their source before they escape into the workroom environment. The main advantage of local exhaust systems is that they remove contaminants rather than just dilute them. Even with LEV, some airborne contaminants may still be in the workroom air due to uncontrolled sources or less than 100% collection efficiency at

the hoods. A second major advantage of local exhaust is that these systems require less airflow than dilution ventilation systems in the same applications. The total airflow is especially important for plants that are heated or cooled since heating and air conditioning costs are an important operating expense.

LOCAL EXHAUST SYSTEM COMPONENTS

A typical local exhaust system consists of the following elements (Figure 19–1):

- ➢ *Hoods*—any point where air is drawn into the ventilation system to capture or control contaminants. Some hoods are designed to fit around existing machinery while others are located next to the contaminant source. Even a plain duct opening is called a "hood" if that is where air enters the system. Different hoods work in different ways: some reach out and capture contaminants; others catch contaminants thrown into the hood; still others contain contaminants released inside the hood and prevent them from escaping into the workroom. Some hood designs feature a long, narrow slot to distribute the airflow along the length of an open surface tank, welding bench, or laboratory hood.
- ➢ *Ducts*—the network of piping that connects the hoods and other system components.
- ➢ *Fan*—the air-moving device that provides the energy to draw air and contaminants into the exhaust system and through the ducts and other components. It functions by inducing a negative pressure or suction in the ducts leading to the hoods and positive pressure in the system after the fan. The fan converts electrical power into pressure and increased air velocity.
- ➢ *Air Cleaner*—a device to remove airborne materials that may be needed before the exhaust air is discharged into the community environment. Air cleaners to remove both solid (particulate) and gaseous contaminants are available.

Although not formally part of an LEV system, the arrangement for supplying makeup air to the work area that is being ventilated is also very important. An insufficient quantity of makeup air may cause poor fan operation, inefficient combustion in furnaces, drafts, and problems with slamming doors in the work area.

An LEV system is usually planned to fit existing machinery or industrial processes. A hood shape and location are chosen based upon the source of contamination. The airflow volume into each hood is then determined from reference sources such as the ACGIH *Industrial Ventilation Manual* (ACGIH, 1998). Next, the need for an air cleaner is determined, and, if needed, a type and size are selected. With this information the duct layout can be determined and the duct diameters calculated. Finally, the fan type and size needed to draw the required amount of air while overcoming friction and other resistance can be determined. After installation, the system is tested to assure that it is meeting design criteria. System design is beyond the scope of this chapter; however, the references listed at the end of Chapter 20 describe how to design LEV systems (McDermott, 2000; ACGIH, 1998).

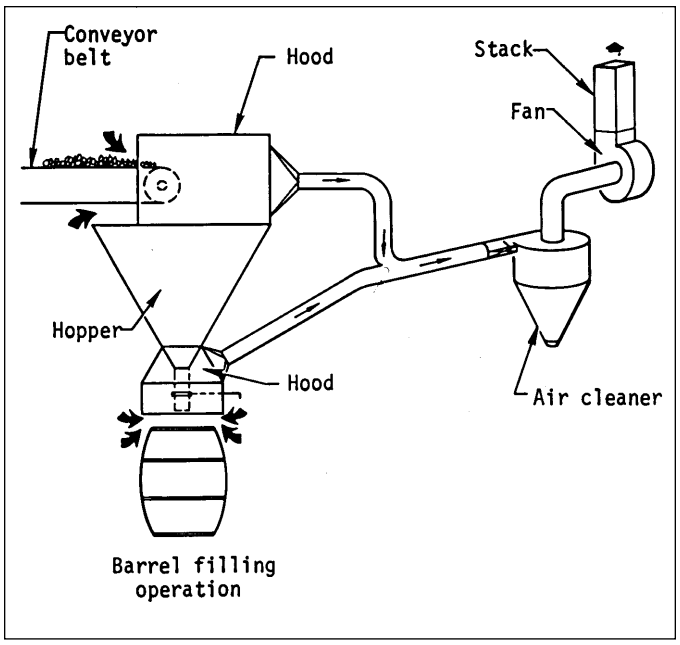


Figure 19–1. Typical Local Exhaust Ventilation system. (Source: McDermott, 2000.)

Hoods

The hood is the most important part of an LEV system. No local exhaust system will work properly unless enough of the contaminants are retained or captured by the hoods to reduce the concentration in the workroom air below acceptable limits. Both the design and location of the hoods are critical in determining whether a system will work. A poor hood design may prevent the ventilation system from performing adequately.

Hood selection is an area where the health and safety professional can make a significant contribution since the keys to good hood selection include the following: a knowledge of hood and airflow principles, an understanding of the plant processes, and a familiarity with employee work patterns around each process. In many plants, the health and safety staff has the best overall understanding of these three areas. Fortunately, once the fundamentals of hood selection are understood, there is a ready reference source for specific hood designs. The ACGIH *Manual* contains almost 150 design plates showing layout, design parameters, and airflow recommendations for different hoods (ACGIH, 1998).

HOOD TYPES

Three different types of hoods are used in local ventilation systems: capturing hoods, enclosures, and receiving hoods. Each works according to one of the following principles to control contaminants:

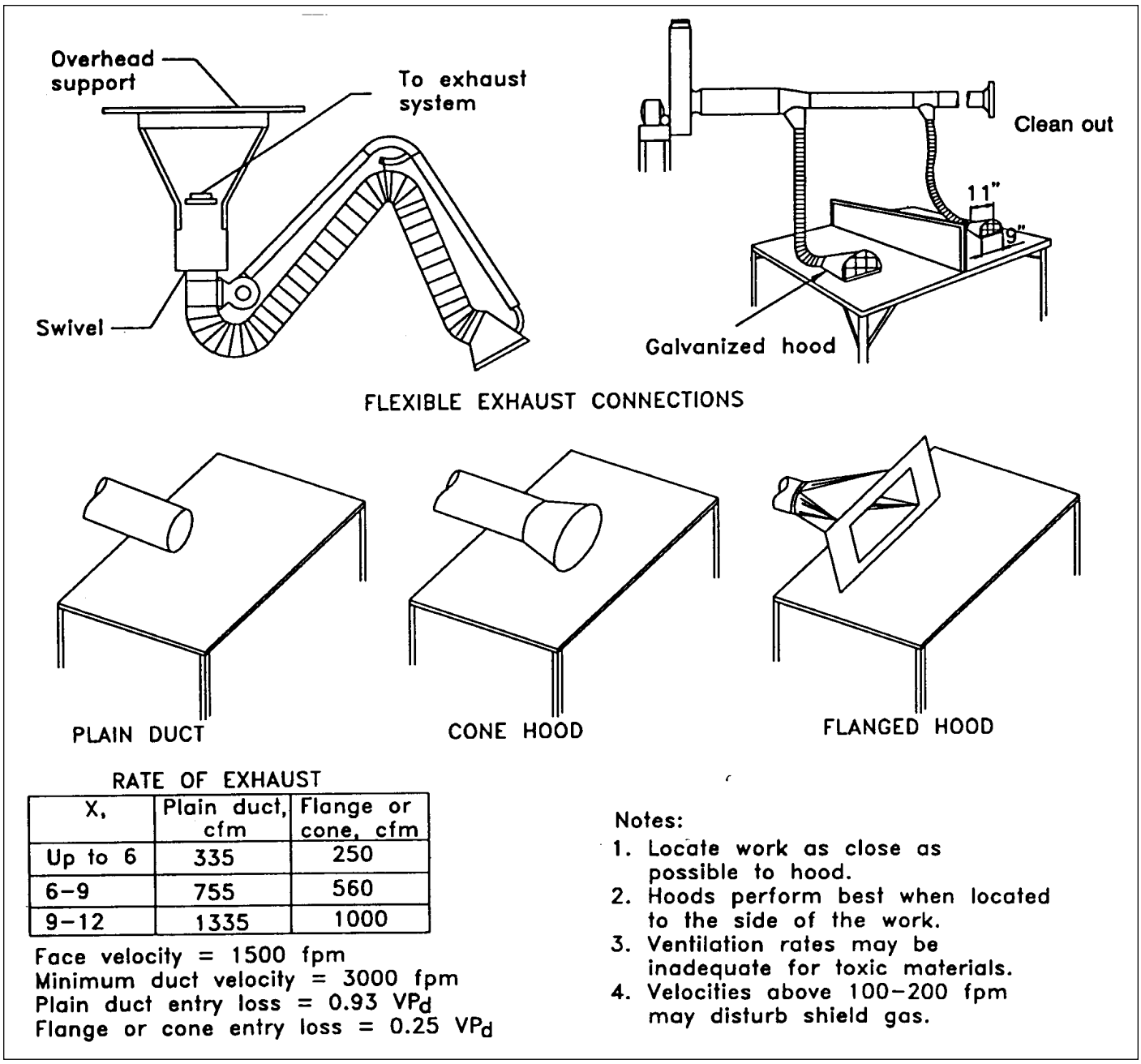


Figure 19–2. Capturing hood for welding fumes. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

➢ *Capturing Hoods*—Hoods that "reach out" to capture contaminants in the workroom air (Figure 19–2). Airflow into the hood is calculated to generate sufficient capture velocity in the air space in front of the hood. The needed capture velocity depends on the amount and motion of contaminants and contaminated air (Table 19–A). This type of hood is widely used since it can be placed alongside the contaminant source rather than surrounding it as with an enclosure. The primary disadvantage is that large air volumes may be needed to generate an adequate capture velocity at the contaminant source. Other disadvantages are that crossdrafts in the workroom can severely degrade the capture efficiency of the hood, and the "reach" of most capturing hoods is limited to about 2 ft from the hood opening.

➢ *Enclosures*—Hoods that surround the contaminant source as much as possible. Contaminants are kept inside the enclosure by air flowing in through openings in the enclosure (Figure 19–3). Laboratory hoods and paint spray booths are typical examples of this hood type. The quantity of air required for contaminant control is calculated by multiplying the inward air velocity needed to

Table 19–A. *Range of Capture Velocities*

Dispersion of Contaminant	*Examples*	*Capture Velocity, ft/min*
Released with practically no velocity into quiet air.	Evaporation from tank; degreasing.	50–100
Released at low velocity into moderately still air.	Spray booths; intermittent container filling; low-speed conveyor transfers; welding; plating; pickling.	100–200
Active generation into zone of rapid air motion.	Spray painting in shallow booths; barrel filling; conveyor loading; crushers.	200–500
Released at high initial velocity into zone of very rapid air motion.	Grinding; abrasive blasting; tumbling.	500–2000

In each category above, a range of capture velocities is shown. The proper choice of values depends on several factors:

Lower End of Range	*Upper End of Range*
1. Room air currents minimal or favorable to capture.	1. Disturbing room air currents.
2. Contaminants low toxicity or of nuisance value only.	2. Contaminants of high toxicity.
3. Intermittent, low production.	3. High production, heavy use.
4. Large hood-large air mass in motion.	4. Small hood-local control only.

(Source: From American Conference of Governmental Industrial Hygienists (ACGIH®) *Industrial Ventilation: A Manual of Recommended Practice*, 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

prevent escape by the areas of the openings into the enclosure. The more complete the enclosure, the less airflow is needed for control. Employees generally do not work inside enclosures while contaminants are being generated, although they may reach into the enclosure as long as they do not breathe contaminated air. Due to low exhaust rates, enclosures are often the most economical hoods to install if the open area of the enclosure is not large. Inward face velocities of 100–150 ft/min are typical. Good room conditions are critical for proper enclo-

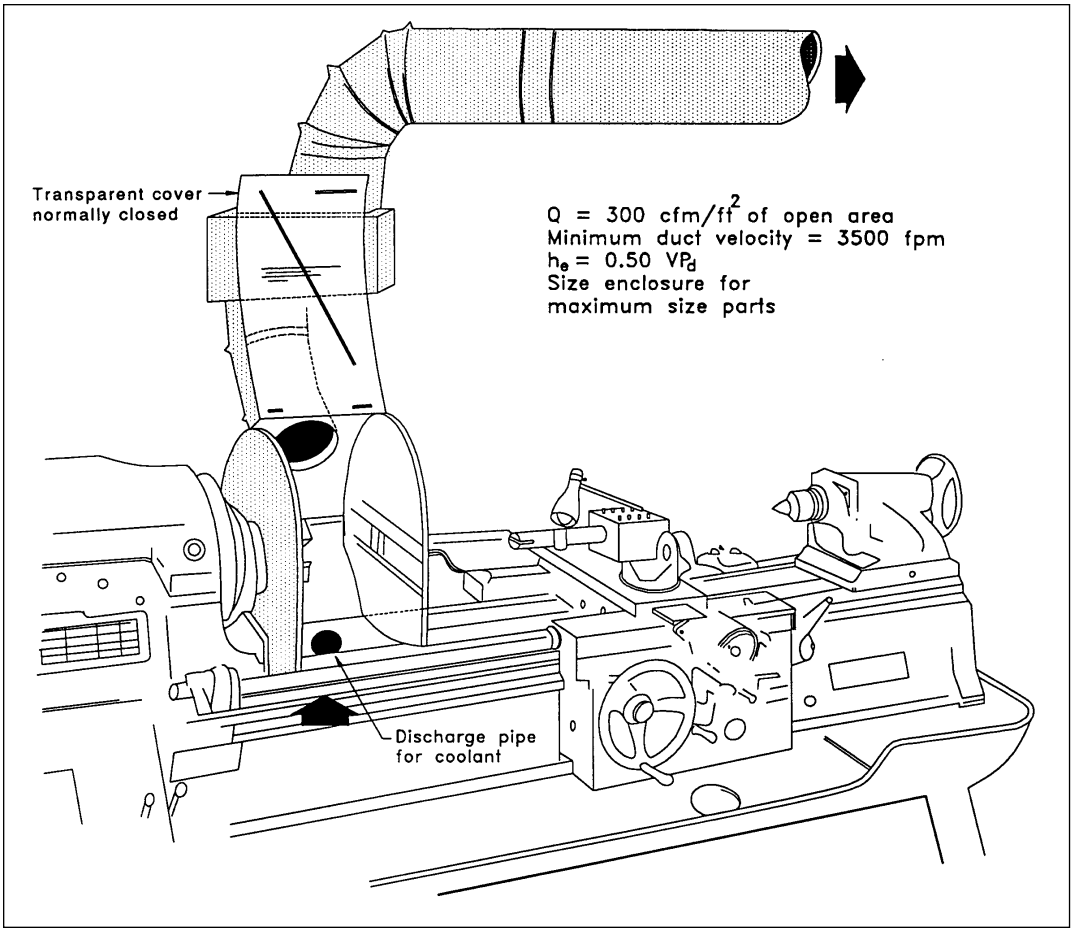


Figure 19–3. Design details for an enclosure from the ACGIH *Manual.* (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

sure performance, including sufficient replacement air, supply outlets located and designed to avoid drafts, and protection against disruptive air currents from open doors and foot traffic near the hoods.

➢ *Receiving Hoods*—Some processes "throw" a stream of contaminants in a specific direction. For example, a furnace may emit a hot stream of gases that rises above the unit. A grinder throws a stream of material tangentially from the point of contact between the grinding wheel and workpiece. The ideal hood for this type of process is one that is positioned so it catches the contaminants thrown at it (Figure 19–4). A major limitation to the use of receiving hoods is that gases, vapors, and the very small particles that can be inhaled and retained in the human respiratory system do not travel very far in air unless carried by moving air. This means that receiving hoods are not very useful for health protection ventilation systems unless the process emits quantities of hot air or air with sufficient velocity to carry the respirable contaminants into the hood.

In addition to these three major hood classifications, two special hood types are used in LEV systems:

➢ *Slot Hoods*—Some capturing hoods and enclosures feature a narrow "slot" to distribute the inward airflow across the entire hood. By definition, a slot is at least five times as long as it is high. A typical example is a long, open surface tank that has limited space for a hood yet has a need for good air distribution over its entire length (Figure 19–5). Similarly, a laboratory hood has slots along the back panel to develop more uniform air velocity through the hood opening. One disadvantage of a slot hood is that it creates more energy loss than a hood without a slot. This is due to the turbulence and high air velocity through the narrow slot. Extra suction is needed to move the air through the slot, which requires a larger fan than for a comparable system with no slot.

It is important to realize that a high slot velocity does not significantly increase the reach of the hood. The purpose of the slot is solely to distribute the inward velocity along the length of the slot. As a rule-of-thumb, a slot velocity of 2,000 ft/min often gives good air distribution without excessive pressure loss.

➢ *Canopy Hoods*—A canopy hood (Figure 19–6) generally can be used only as a receiving hood over hot processes to collect the gases and vapors rising into the hood. However, a canopy cannot be used when workers must lean over the tank or process because workers will breathe the contaminated air as the contaminants rise.

Canopies for *unheated* processes must be designed as capturing hoods. However, the large airflow volumes needed to develop adequate velocities below the canopy plus the two-foot limitation on capture distance often make these hoods impractical. The solution is another type of capturing hood, such as a side draft or slot hood, or an enclosure.

Ducts

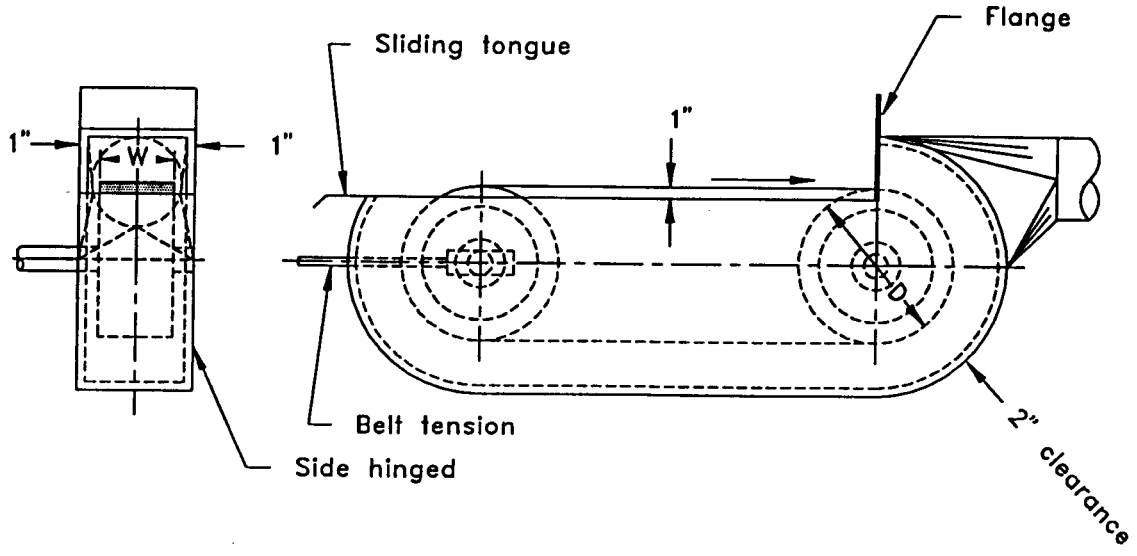
Ducts carry air between the hoods, air cleaner, fan, and discharge stack. Common duct materials for LEV systems include galvanized steel, aluminum, stainless steel, plastics, and wire-wrapped fabric flexible duct. Stainless steel and specialty plastics are used where protection against corrosion is needed. Wire-wrapped flexible fabric ducts are often not recommended for LEV systems carrying particulates because of their tendency to accumulate settled material and sag unless rigidly supported, and because of the difficulty in cleaning out settled material.

Selecting duct diameters for a system is often a trade-off between initial and operating cost. Smaller diameter ducts are less expensive to fabricate and install than larger diameter ducts. However, the resulting higher duct velocities in smaller diameter ducts increase pressure losses, thus requiring a larger fan with higher power consumption. Systems carrying particulates generally need to maintain a certain minimum transport velocity to avoid material settling in the ducts. For common dusts, this velocity is often 3,000–4,000 ft/min. For more dense materials, larger particles, or sticky materials, the minimum velocity needed is higher. Although systems handling vapors and gases have no minimum duct velocity criteria, as a rule-of-thumb, duct velocities of 2,000–3,000 ft/min usually result in a good balance between initial duct construction cost and fan operating cost. Hood design diagrams in the ACGIH *Manual* usually specify duct velocity criteria for the system.

Air movement is always accompanied by friction where the air meets the duct surface. As a result, the air velocity close to the duct wall is low while at the center of the duct the velocity is higher than the overall average value. Figure 19–7 depicts a very simplified view of the duct velocity profile; any disturbances to smooth airflow such as elbows, branch duct entries, or air cleaners cause an uneven distribution that gradually returns to the typical profile illustrated in the figure.

In addition to friction, turbulence occurs in the ducts due to changes in air velocity and direction. Some loss will occur at every hood, elbow, duct enlargement, or duct junction. Since the fan must be large enough to move the required quantity of air while overcoming the friction and turbulent losses, it is important to avoid duct features that cause unnecessary pressure drop. These include narrow ducts, small radius elbows, and perpendicular junctions where two ducts join.

Another duct consideration is the duct segment just before the fan. The fan can do the greatest amount of work on incoming air only if the airflow into the fan is straight and uniform. Spinning or nonuniform flow patterns reduce the fan's air volume and/or static pressure output. Major reasons for poor flow patterns are elbows, dampers, duct junctions, or other flow disturbances near the fan. For an existing system, installing flow straighteners in the inlet duct can help to restore straight flow into the fan.



Belt width, inches	Exhaust flow rate, cfm
Up to 3	220
3 to 5	300
5 to 7	390
7 to 9	500
9 to 11	610
11 to 13	740

Minimum duct velocity = 3500 fpm, 4500 fpm if material is wet or sticky

h_e = 0.65 VP_d for straight take-off
= 0.45 VP_d for tapered take-off

Notes:
1. Consult applicable NFPA codes.
2. Caution: Do not mix ferrous and nonferrous metals in same exhaust system.

Figure 19–4. Metal polishing belt—design details for a receiving hood from the ACGIH *Manual.* (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice*, 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

The ACGIH *Manual* contains guidelines for other duct design parameters, such as pressure loss factors, provisions for clean-out ports, and duct wall thickness.

EXHAUST STACKS

Every LEV system should have at least a short, straight duct or exhaust stack attached to the fan outlet. This helps to change high, uneven velocity patterns at the fan outlet into a uniform flow and results in a phenomenon called *static pressure regain.* This permits the fan to be more efficient in moving air through the system.

The proper stack height, location, and discharge velocity are important in minimizing reentry of exhausted contaminants into the building and in avoiding problems when the

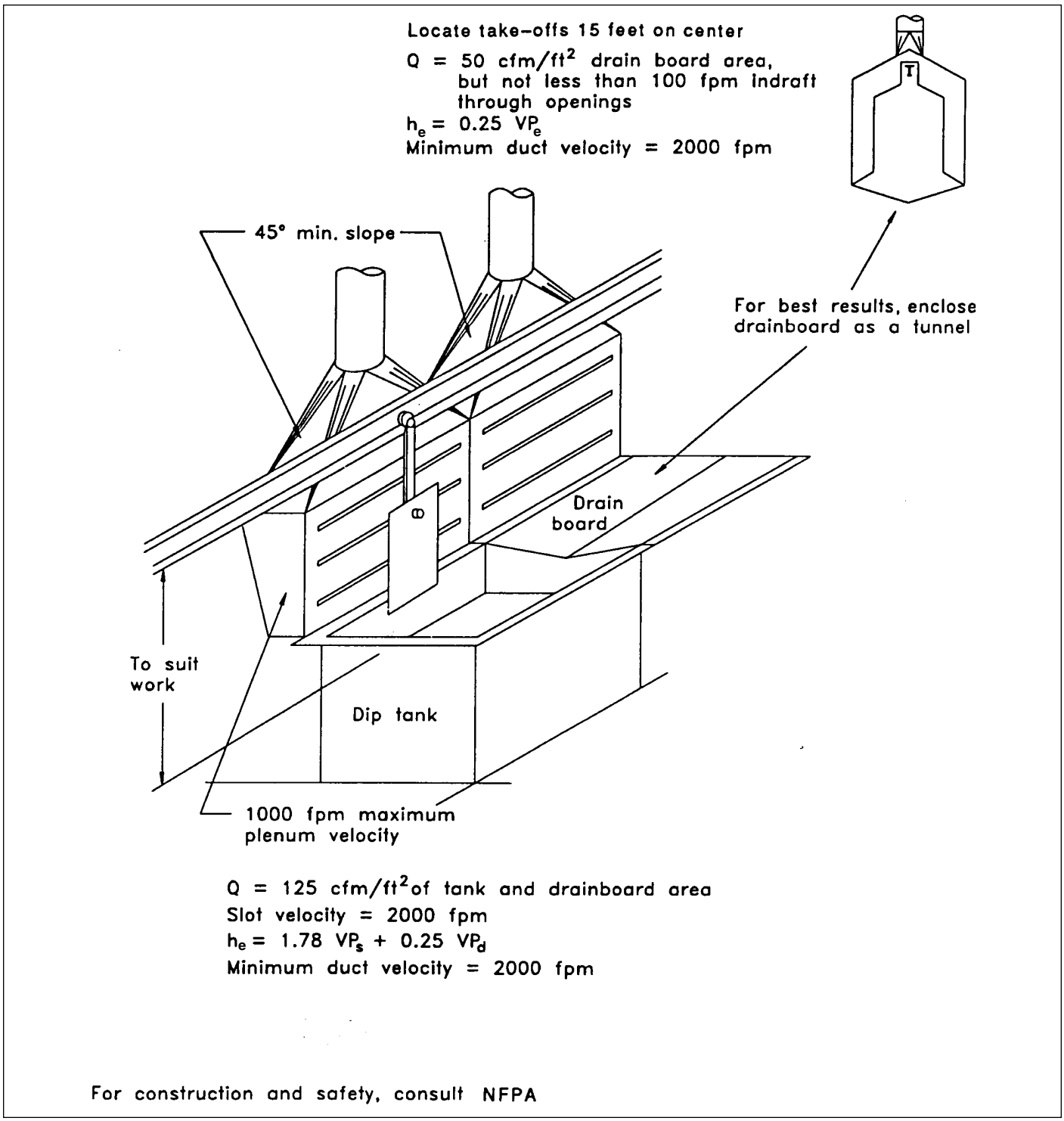
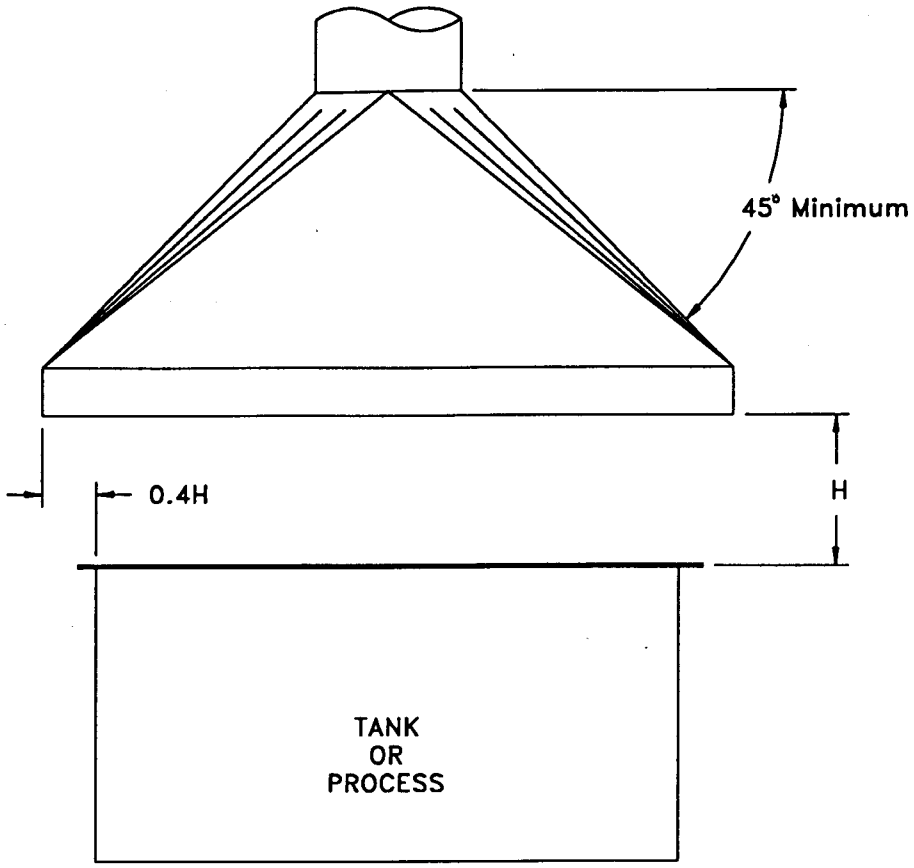


Figure 19–5. Slot hood to distribute airflow along an open surface tank. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

contaminants reach ground level. Airflow patterns around buildings are complex, consisting of several discrete air turbulence and recirculating zones. Generally, the air layers near the roof tend to wash across the roof or circulate so they hit the downwind side of the building or the ground. The exhaust plume should be discharged above these layers so it will not contaminate intakes, and where sufficient dilution occurs before the plume reaches the ground or adjacent buildings. A high stack discharge velocity (3,000 ft/min or higher) helps to disperse contaminants since the air jet action



Not to be used where material is toxic and worker must bend over tank or process.
Side curtains are necessary when cross drafts are present.

Q = 1.4PHV	For open type canopy P = perimeter of tank, feet V = 50–500 fpm.
Q = (W + L)HV	For two sides adjacent enclosed W & L are open sides of hood V = 50–500 fpm.
Q = WHV or LHV	For three sides enclosed (booth) V = 50–500 fpm.

$h_e = 0.25\ VP_d$
Duct velocity = 1000–3000 fpm

Figure 19–6. Canopy hoods are usually used over hot processes since the contaminants rise into the hood. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

can increase the effective stack height except under severe wind conditions.

Wind direction and velocity are other important factors. If there is a prevailing wind direction at the site, it should help to locate the stack on the downwind side of the roof. However, the location of the stack and air intakes should recognize that wind will often blow from other than the prevailing direction. A very low wind speed allows the plume to

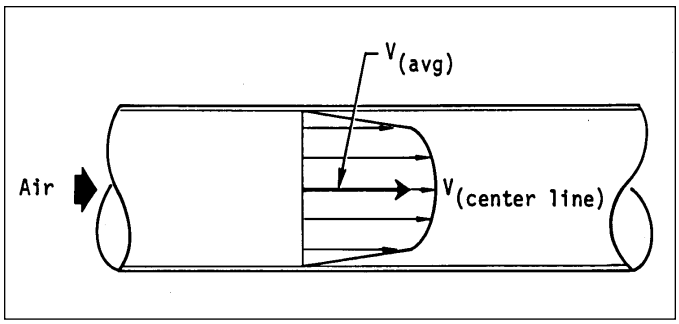


Figure 19–7. Velocity distribution in a duct. The average duct velocity is less than the centerline velocity. (Source: McDermott, 2000.)

rise due to the discharge velocity and any thermal head. As wind velocity increases, the first effect will be to decrease plume rise and the resulting dilution. Still higher winds will increase turbulence, which increases the dilution. Unfortunately, the occurrence of some reentry usually cannot be ruled out, so in very sensitive situations, air cleaners on the discharged air or relocation of air intakes may be needed to eliminate problems.

Fans

The fan generates the suction in the system that draws contaminated air into the hoods and through the ducts. A variety of different fans are available, but they all fall into one of two main classes: centrifugal fans or axial flow fans. Centrifugal fans move air by centrifugal action. Blades on a rotating fan wheel throw air outward from the center inlet at a higher velocity or pressure than air entering the fan. With axial fans, the air travels parallel to the fan shaft and leaves the fan in the same direction as it entered. A screw or propeller action produces airflow.

In LEV systems, centrifugal fans are more widely used than axial fans because they are usually quieter, less expensive to install and operate, and generate higher pressures than axial flow fans of the same airflow capacity. Centrifugal fans can be divided into three categories depending on the shape and setting of the fan wheel blades (Figure 19–8):

- ➢ *Radial-blade fans* (Figure 19–8a) have flat blades that extend straight out from the center hub. They are used for dust systems since their flat blades minimize the buildup of dust on the blades. These fans also have large openings between blades and are therefore less likely to clog. They can be built with thick blades to withstand erosion and impact damage from airborne solids. Their major disadvantage is that they are the least efficient fan for local exhaust systems. Their heavy construction adds to their cost.
- ➢ *Forward-curved blade fans* (Figure 19–8b) are useful when large volumes of air must be moved against moderate pressures with low noise levels. These fans have many cup-shaped blades that accelerate the air and discharge it at a higher velocity than the fan wheel tip is moving.
- ➢ *Backward-inclined/backward-curved blade fans* have blades that are inclined backward from the direction of fan wheel rotation (Figure 19–8c). The blades are of uniform thickness. If they are straight (flat), the fan is called a *backward-inclined blade fan*; if the blades are curved back, the fan is called a *backward-curved blade fan*. Since these fans are more efficient than the forward-curved fan, they are often used for handling large volumes of air containing little dust. *Airfoil* fans are a modification of the backward-curved blade fan. The blades of airfoil fans are shaped like the cross section of an airplane wing. This shape reduces noise and allows the fan to function smoothly without pulsing airflow through its entire operating range.

Fans perform at their maximum efficiency only when the airflow into the fan is smooth. Any design feature in the system that causes turbulence or spinning air motion at the fan inlet will reduce the fan's ability to move air and generate pressure. The most common cause of inlet problems is a duct elbow too close to the fan inlet. Elbows should be at least five duct diameters from the fan inlet unless turning vanes in the elbow or another method is used to straighten the airflow.

An elbow too close to the fan outlet will also decrease performance because of the high velocity, turbulent flow at the outlet. Elbows should be at least five duct diameters, and preferably 10 diameters, away from the fan outlet.

Air-Cleaning Devices

The purpose of this section is to give a broad overview of the types of air cleaners that are available. An important step in

Figure 19–8. Common types of centrifugal fans. (Source: McDermott, 2000.)

system design is the determination of whether an air cleaner is needed to reduce the amount of contaminants discharged to the environment. Local regulations usually are the major factor is this decision.

The ideal air cleaner for a specific application would have these features: low initial and operating cost, high efficiency for the contaminants, no decline in operating efficiency or any service interruptions between scheduled cleaning and maintenance cycles, and provisions for normal maintenance and cleaning without hazardous employee exposures.

The types of devices to consider depend primarily on the physical state of the contaminants (i.e., whether they are particulates or gases/vapors). For most situations, no single device is highly efficient for both small particulates and for gases/vapors. Scrubbing devices are widely used to collect some particles and gases or vapors in a single unit, but these combination units are generally not highly efficient for fine particles.

PARTICULATE REMOVAL

Typical air cleaners for particulates include the following:

- *Filters* trap particulates as the exhaust gas flows through a porous medium. Filters may be made of woven or felted (pressed) fabric, paper, or woven metal, depending on the application. They are available in a variety of configurations, such as mats, cartridges, bags, and envelopes. Filters have the general advantage of being able to handle varying exhaust gas flow rates and particle loadings. Filter devices fall into two major categories: disposable filters that often use inexpensive materials and are available in different configurations, and reusable filter elements in a housing that is equipped with a cleaning mechanism for periodic removal of trapped material. Selection of disposable or reusable filters is based on the expense of replacing the elements versus the added initial cost of the filter-cleaning mechanism.
- *Electrostatic precipitators* charge particles by means of an electric field that is strong enough to produce ions that adhere to the particles. The charged particles are then collected with a weaker electric field that causes the particles to migrate toward and adhere to the electrode with the opposite charge. Precipitators find greatest use in systems where gas volume is large and high collection efficiency for small particles is needed.
- *Cyclones* impart a circular motion to the exhaust gas that causes particulates to move to the outer part of the airstream where they impact the cyclone walls. Since air velocity is lower at the wall, the particulates drop down the wall into a collection hopper at the bottom. Cyclones may also be operated as wet collectors if a water spray is installed to wet the particles at the inlet. This increases the effective size of small particles, thus increasing collection efficiency.
- *Wet scrubbers* contact particles with water or another liquid and then collect the droplets. To collect extremely fine particles, it is necessary to generate small droplets moving at high speed. Scrubbers can remove particles as small as 0.2 μm; however, the energy required to generate small droplets and cause adequate contact rises exponentially as the particle size decreases. Scrubbers that utilize absorption or chemical reaction as a collection mechanism are also widely used for gas and vapor removal.

The "baghouse" (Figure 19–9) is a typical example of a particulate air cleaner. It consists of tubular fabric filters arranged in a housing along with the cleaning mechanism, which can be an automatic or manual shaking device, a means of blowing air back through the bags from the clean side, or another method of dislodging the accumulated dust cake. Chunks of the cake that are dislodged during the cleaning cycle should be large enough so that they are not reentrained in the exhaust gas stream, or the section being cleaned should be isolated from the remainder of the baghouse during its cleaning cycle. Baghouses can collect practically all particles greater than 1 μm in diameter as well as a large percentage of submicron particles.

GAS AND VAPOR REMOVAL

Major removal techniques for gases and vapors are absorption, adsorption, and oxidation:

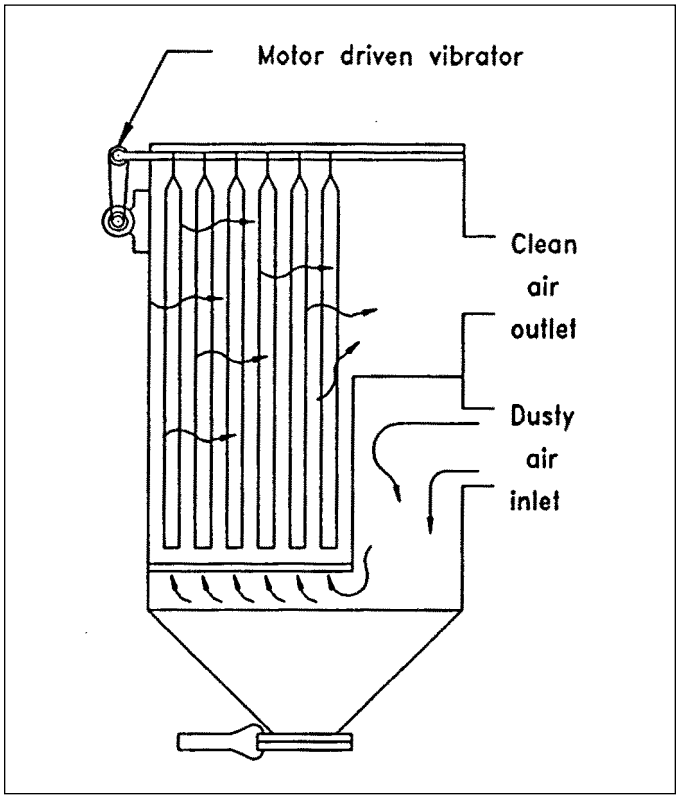


Figure 19–9. Typical baghouse air cleaner. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

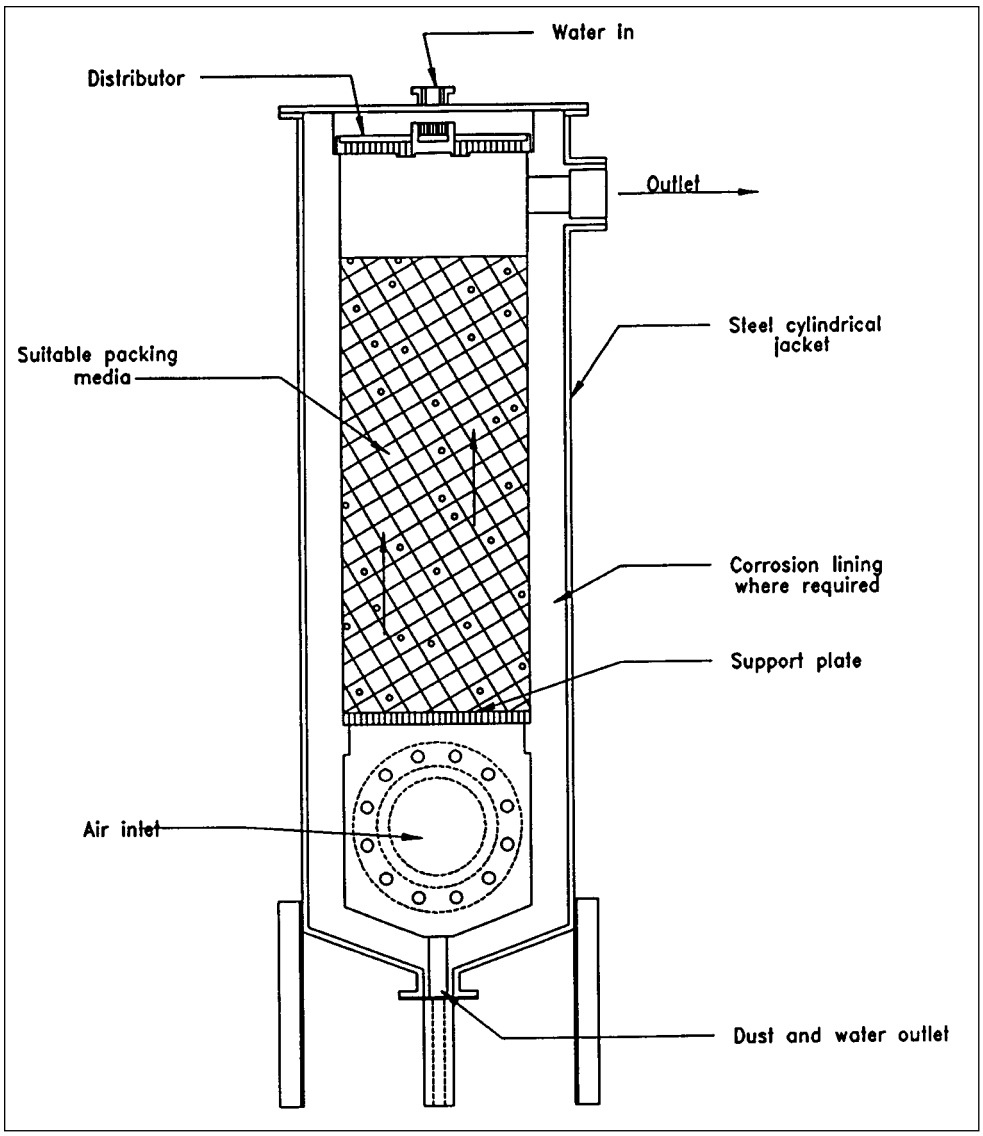


Figure 19–10. Typical packed bed air cleaner. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

- *Absorption* is a diffusion process in which molecules are transferred from the exhaust gas to a liquid. The diffusion occurs because there is a gradient between the contaminant concentration in the exhaust gas and the liquid phase. This causes the contaminant to move from the higher level in the gas phase to the lower concentration in the liquid. The laws of mass transfer govern absorption. Mass transfer occurs at the interface between the gas or vapor molecule and the liquid and is enhanced by the following factors:
  - high interfacial area between the exhaust gas and the liquid
  - turbulent contact between the two phases
  - high solubility of the gas or vapor in the liquid phase
  - higher temperature, which affects solubility

For easily absorbed contaminants, a spray chamber or another simple device may work. However, for materials with low solubility or where a chemical reaction occurs between the contaminant and liquid prior to absorption, a packed bed (Figure 19–10) is often used to maximize contact. Reactive scrubbing is a special case of gas/vapor scrubbing. In reactive scrubbing, the contaminant reacts with the liquid to form a compound that is retained in the liquid.

- *Adsorption* is the process in which a gas or vapor adheres to the surface of a porous solid material. It occurs when the contaminant condenses into very small liquid droplets at an ambient temperature higher than its boiling point. This principle is well-known to industrial hygienists through use of activated carbon sampling devices. Since no chemical reaction is involved, adsorption is reversible. The contaminant can be recovered, if warranted, from the adsorbent by heating, steam flushing, air stripping, vacuum treating, or any other method that vaporizes the condensed material. Removing the adsorbate regenerates the adsorbent for further use. In addition to activated carbon, popular adsorbents include silica gel and molecular sieves.
- *Oxidation or combustion* devices can be used when the air contaminants are combustible. They oxidize (burn) the

contaminants under a variety of operating conditions. Many are designed for gases and vapors; often these do not work well when the airstream contains particulates. They are very useful for processes that release extremely odorous organic vapors and fumes. The major expense associated with combustion systems is the auxiliary fuel needed to heat incoming exhaust gas and assure complete combustion. Some devices use a catalyst that causes the contaminant to oxidize at a lower temperature than normal in order to save fuel. Since most LEV systems exhaust room air with very low levels of contaminants, combustion is often not cost-effective. Combustion devices find more application with process vents or similar sources where the contaminant concentration is relatively high.

Makeup Air

Makeup air is air that enters the workroom to replace air exhausted through the ventilation system. A room or plant with insufficient makeup air is said to be "air bound" or "air starved." A ventilation system will not work properly if there is not enough air in the room to exhaust. This means that if the ambient static pressure within the room becomes slightly negative, the fan may not work properly against this additional resistance.

Makeup air should be supplied through a planned system rather than through random infiltration. The system should have the following features:

- ➢ The supply rate should exceed the exhaust rate by about 10%. This slight positive pressure in the building helps to keep out drafts and dust. The exception is a situation where no dust or airborne chemicals should travel from the workroom to adjacent offices or other areas. Then a slight negative pressure inside the workroom is preferred.
- ➢ The air should flow from cleaner areas of the plant through areas where contaminants may be present and finally to the exhaust system. Flow should also be from normal temperature areas to high heat process areas. The makeup air supply system can be designed to provide some cooling in the summer in hot process areas.
- ➢ Makeup air should be introduced into the "occupied zone" of the plant, generally 8–10 ft from the floor. This gives the workers the benefit of breathing fresh air and, if the air is tempered (heated or cooled) maximizes the comfort provided by the makeup air.
- ➢ The air should be heated in winter to a temperature of about 65 F.
- ➢ Makeup air inlets outside the building must be located so that no contaminated air from nearby exhaust stacks or chimneys is drawn into the makeup air system.

AIRFLOW AND PRESSURE PRINCIPLES

This section describes the principles that govern LEV system operation. The information is useful in understanding how the components described above function, and how to test and upgrade an installed system. The principles fall into two broad categories: *airflow* and *pressure*.

Airflow Principles

The basic airflow concept in ventilation systems is called the "equation of continuity," which expresses mass balance as air flows through different parts of the system. The equation of continuity is expressed as follows:

$$Q = V \times A \quad (1)$$

where Q = airflow, ft^3/min
V = air velocity, ft/min
A = area of airflow, ft^2

At each point in a closed system (no additional air entering the duct):

$$Q = V_1 \times A_1 = V_2 \times A_2 \quad (2)$$

where $_{1, 2}$ = two locations within the closed system

These equations have several important applications, including the following:

- ➢ The volumetric airflow (Q) through an opening (doorway, laboratory hood face) or in a duct can be readily determined using Equation (1) by measuring the average air velocity through the duct or opening and the area of the duct or opening.
- ➢ After Q is calculated or measured at one location in an LEV system, the velocity at other locations can be calculated from the Q and cross-sectional area at the new location, using Equation (2). This calculation is valid as long as no additional air enters the system through another hood. The calculation is useful to assure that adequate duct velocity is maintained at different parts of the system as duct diameter changes or to select the stack diameter to give a high discharge velocity for dispersion.

Another useful set of equations describes the relationship between volumetric airflow (Q) into a hood and the capture velocity generated out in front of the hood. These are shown in Figure 19–11 for different capture hood types. The equations can either be used to calculate the Q needed to generate the required capture velocity at X distance in front of the hood or to determine the velocity that will be generated by a given value of Q.

It important to note that these equations refer only to the centerline velocity, which is the air velocity along a line extending out from the center of the hood or duct, and do not describe the velocity distribution across the hood opening. Also, any distance X may be substituted into the equations to give an answer, but in practice a capturing hood can only reach out about two feet to draw in contaminants.

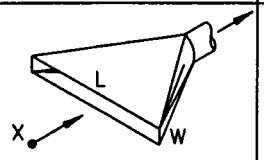
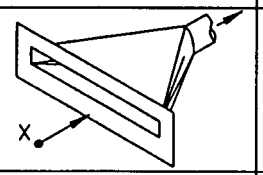
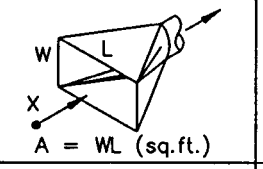
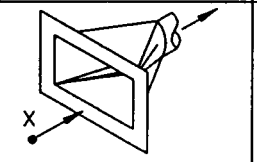
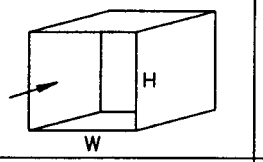
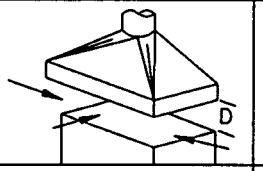
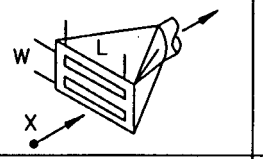
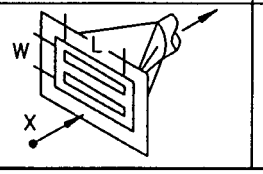
HOOD TYPE	DESCRIPTION	ASPECT RATIO,W/L	AIR FLOW
	SLOT	0.2 OR LESS	Q = 3.7 LVX
	FLANGED SLOT	0.2 OR LESS	Q = 2.6 LVX
	PLAIN OPENING	0.2 OR GREATER AND ROUND	$Q = V(10X^2+A)$
	FLANGED OPENING	0.2 OR GREATER AND ROUND	$Q = 0.75V(10X^2+A)$
	BOOTH	TO SUIT WORK	Q = VA = VWH
	CANOPY	TO SUIT WORK	Q = 1.4 PVD SEE VS– 99-03 P = PERIMETER D = HEIGHT ABOVE WORK
	PLAIN MULTIPLE SLOT OPENING 2 OR MORE SLOTS	0.2 OR GREATER	$Q = V(10X^2+A)$
	FLANGED MULTIPLE SLOT OPENING 2 OR MORE SLOTS	0.2 OR GREATER	$Q = 0.75V(10X^2+A)$

Figure 19–11. Equations for calculating air flow (Q) for common hood types. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

For example, the centerline velocity outside a freely hanging plain hood (see Figure 19–11) is found by using the following equation:

$$Q = V_x (10X^2 + A) \quad (3)$$

where V_x = air velocity at X distance, ft/min
Q = airflow into hood, ft^3/min
A = area of hood face, ft^2
X = distance outward from hood along hood axis (i.e., centerline), ft

Figure 19–12 (left diagram) shows the velocity contours in front of this hood type. The contours show that the velocity drops off significantly on either side of the centerline. One reason for this is that the hood draws air from behind the hood outside the contamination zone.

The plain hood can be easily improved by adding a flange or collar to reduce the air drawn from behind the hood as shown in Figure 19–12 (right diagram). This decreases the airflow requirement needed to develop the same V_x by about 25% for a flanged hood compared to a plain hood and changes the previous equation to the following:

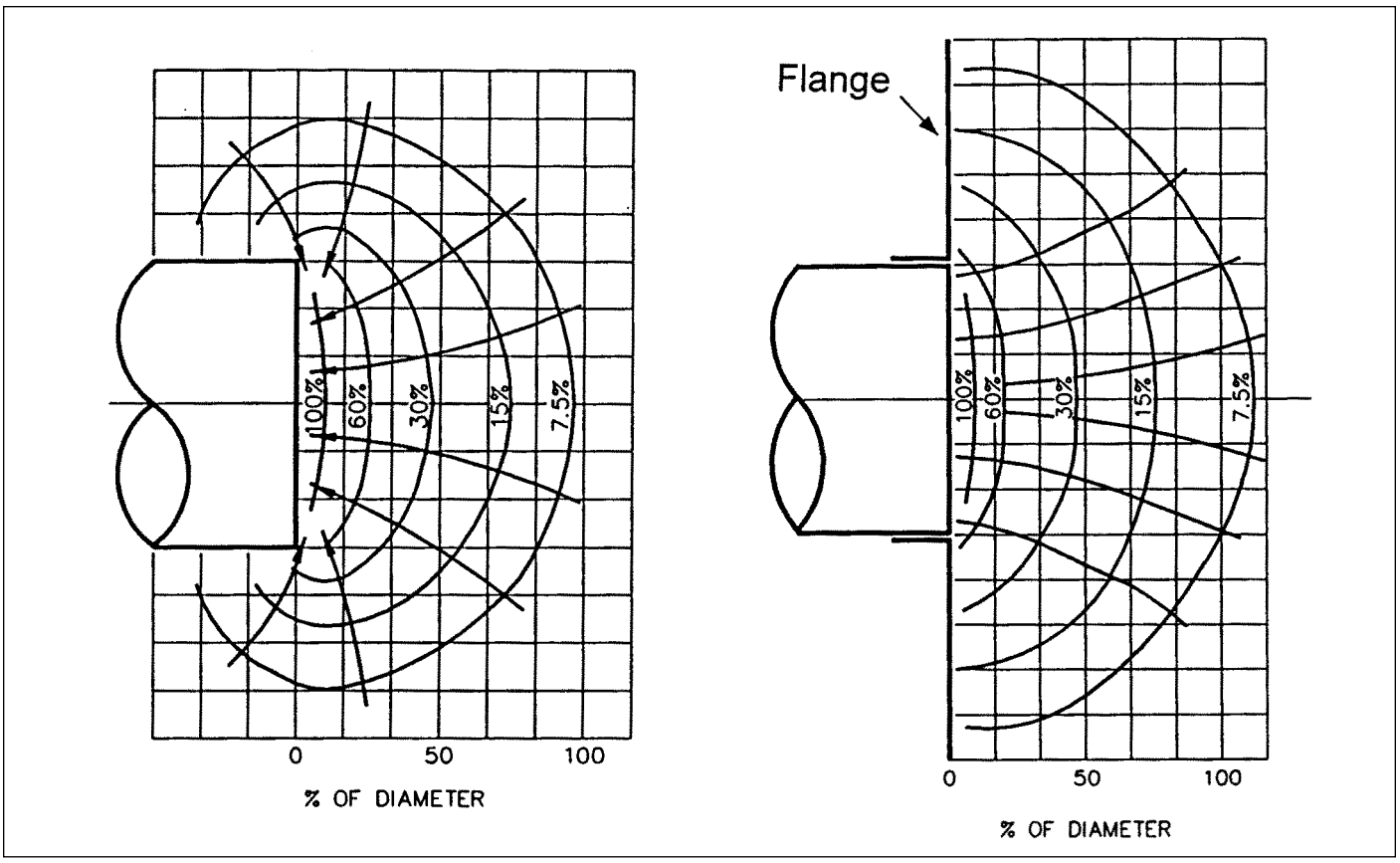


Figure 19–12. Velocity profile in front of a plain hood (left) and flanged hood (right). The flange reduces the quantity of air drawn from behind the hood so there is more inward air velocity along the centerline. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice*, 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

$$Q = 0.75\,V_x\,(10X^2 + A) \qquad (4)$$

Example: A 4 in. x 8 in. (area = 32 in.^{2} or 0.22 ft^2) flanged suspended hood is drawing 500 ft^3/min of air. What is the velocity 6 in. (0.5 ft) in front of the hood?

Answer:

$$Q = 0.75\,V_x\,(10X^2 + A)$$

$$500\ \text{ft}^3/\text{min} = 0.75\,V_x\,[10(0.5^2) + 0.22] = 0.75\,V_x\,[10(0.25) + 0.22]$$

$$500\ \text{ft}^3/\text{min} = 0.75\,V_x\,[2.50 + 0.22] = 0.75\,V_x\,[2.72]$$

$$V_x = \frac{500\ \text{ft}^3/\text{min}}{(0.75)\,(2.72)} = 245\ \text{ft/min}$$

When considering airflow into hoods, there may be a tendency to assume that heavier-than-air vapors will tend to settle to the workroom floor and can be collected by a hood located there. In reality, for the small amounts of vapor in contaminated air (1,000 ppm means 1,000 parts of contaminants plus 999,000 parts of air), the resulting density of the mixture is so close to that of air that random air currents disperse the materials throughout the room. The exception to this rule is that a sizable leak of a dense gas or vapor (such as a compressed gas that chills by expansion as it escapes) will form a plume that moves along the ground. In this situation, a floor-level hood might be advantageous, but general room concentrations may still be significant.

Pressure Concepts

Air moves because there is a difference in pressure between two points. In an exhaust system, the fan develops negative pressure (suction) that extends back through the ducts to each hood. There the suction starts room air moving into the hoods and through the system. On the discharge side of the fan, positive pressure pushes the air through any remaining ducts and out the stack.

In ventilation work, pressure is expressed in units of "inches of water gauge." This represents the height of a water column (e.g., the weight of water) that the pressure will support. It is equivalent to more common pressure units, such as "pounds per square inch," but is more convenient to use since typical pressures in an LEV system are small. For example, an LEV system may have a maximum static pressure of 5 inches of water, which is equivalent to only 0.2 psi.

Pressure can be measured directly in inches of water using a U-tube manometer (Figure 19–13). The pressure value is

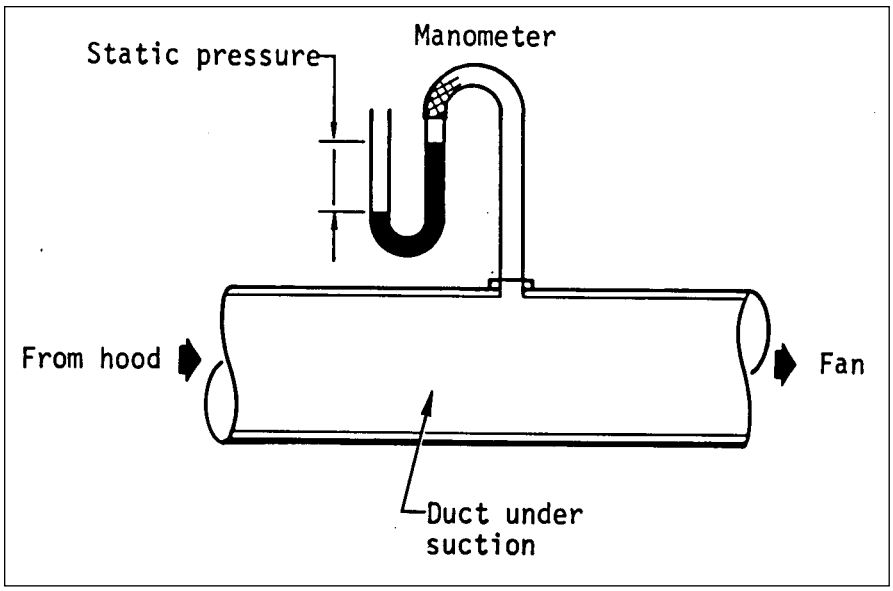


Figure 19–13. Static pressure in "inches of water" is measured with a water manometer. (Source: McDermott, 2000.)

the difference between the water level in each leg of the tube. Mechanical pressure gauges and electronic transducer units calibrated in inches of water are also commonly used.

TWO TYPES OF PRESSURE

A local exhaust system has two types of pressure, static pressure and velocity pressure.

➢ *Static pressure* (either negative or positive) pulls inward on the ducts before the fan and pushes outward on the ducts after the fan. Static pressure in a ventilation system acts to collapse the walls of the ducts on the suction side (inlet) of the fan and to burst the ducts on the discharge side. It acts equally at all locations in the duct (center as well as at the walls). The easiest way to measure it is by using a water manometer to read the bursting force on the duct walls (Figure 19–13), although the same reading will be obtained at any point across the duct at that location. Static pressure can be viewed as potential energy in the system that is available to start air moving and keep it moving by overcoming friction and turbulent losses.

➢ *Velocity pressure* is due to air moving through the system, which represents kinetic energy. Velocity pressure is exerted by air in motion and has a positive sign in the direction of airflow. Velocity pressure is determined by measuring the average velocity at the point, and using the following equation:

$$VP = \left(\frac{V}{4{,}005}\right)^2 \qquad (5)$$

or

$$V = 4{,}005\sqrt{VP} \qquad (6)$$

where VP = velocity pressure, inches of water
V = velocity, ft/min

The equations for velocity pressure assume standard air density, which is 0.075 lb/ft^3. Density is affected by the moisture content and temperature of the air as well as altitude above sea level. Density corrections are needed to velocity pressure readings if any of the following three conditions occur: (1) moisture exceeds about 0.2 pounds of water per pound of air; (2) air temperature is outside the 40 F to 100 F range; or (3) altitude exceeds +1,000 ft relative to sea level. The density correction for temperature and atmospheric pressure can be calculated using the following equation:

$$\text{Density}_{\text{actual}} = \frac{0.075 \text{ lb}}{\text{ft}^3} \times \frac{530 \text{ F}}{(460+\text{t}) \text{ F}} \times \frac{\text{Bar. press}}{29.92} \qquad (7)$$

where $\text{Density}_{\text{actual}}$ = actual air density, lb/ft^3
t = temperature, °F
Bar. press. = Barometric pressure, inches of mercury

For density corrections due to elevated moisture, see the ACGIH *Ventilation Manual*.

With nonstandard air, the velocity pressure equation becomes:

$$VP = \left(\frac{V}{4{,}005}\right)^2 \left(\frac{\text{Density}_{\text{actual}}}{0.075 \text{ lb/ft}^3}\right) \qquad (8)$$

The sum of velocity pressure and static pressure at any point in the system equals the total pressure. The concept of total pressure is not very important in most LEV work, but illustrates that static pressure can be changed into velocity pressure and vice versa without an overall loss of pressure (or energy) from the system.

The concept of pressure governs most aspects of ventilation system operation. For example, room air has almost no velocity so its velocity pressure is zero. The LEV system draws that air into a hood and accelerates it up to the duct

velocity. At that point the air has a velocity pressure value corresponding to that duct velocity according to Equation (5). For this to occur, the system must give up the same amount of static pressure (i.e., the static pressure is converted into velocity pressure).

Example: What is the acceleration loss to accelerate room air up to 2,500 ft/min duct velocity?

Answer:

$$VP = \left(\frac{V}{4{,}005}\right)^2$$

$$VP = \left(\frac{2{,}500}{4{,}005}\right)^2 = (0.62)^2$$

VP = 0.38 inches of water

This means that accelerating room air to 2,500 ft/min duct velocity will cause a loss of 0.38 inches of water suction from the system.

HOOD ENTRY LOSS

In addition to the acceleration loss that occurs at the hood, there is additional loss because turbulence occurs as the air enters the hood and duct. This turbulent loss is called *hood entry loss*, and is separate from acceleration loss.

The energy lost due to turbulence at the hood, expressed in units of "equivalent number of velocity pressures lost," is called the *hood entry loss coefficient (F)* and has been measured experimentally for many hood shapes (Figure 19–14). For a typical hood, the hood entry loss occurs as the air enters the duct at the hood, so the coefficient is referred to as Fd. For hoods with a long, narrow slot to distribute airflow, a loss also occurs at the slot; the coefficient for this loss is called Fs. Most slot hoods have a total hood entry loss made up of separate slot and duct entry components.

A hood shape that does not cause much turbulence has a lower entry loss coefficient than a hood with close clearances, sharp corners, or other features that produce a lot of turbulence. For example, as shown in Figure 19–14, a plain duct opening has a hood entry loss coefficient of about 93 percent of the duct velocity pressure while a smooth, bell-shaped entry reduces the turbulence so that the loss coefficient is just 4 percent of the duct velocity pressure. A narrow slot hood causes such severe turbulence that the slot entry loss coefficient is almost twice the slot velocity pressure.

To calculate the hood entry loss in units of inches of water, multiply the hood entry loss coefficient (F) by the duct or slot velocity pressure. For a hood without a slot, the equation is as follows:

$$h_e = (F_d)(VP_d) \quad (9)$$

For a slot hood, the total entry loss is the sum of the h_e value plus the additional entry loss at the slot, calculated by the following equation:

$$h_{e(\text{slot hood})} = (F_d)(VP_d) + (F_s)(VP_s) \quad (10)$$

where h_e = hood entry loss, inches of water
$h_{e(\text{slot hood})}$ = total hood entry loss for slot hood, including both loss at slot and as air enters duct, inches of water
F_d = duct entry loss coefficient for hood
F_s = slot entry loss coefficient for slot hood
VP_d = duct velocity pressure, inches of water
VP_s = slot velocity pressure, inches of water

The hood design information in Figures 19–2 to 19–6 illustrates the hood entry loss associated with these hood configurations. Specific points include the following:

- ➢ Figure 19–2 (welding hood) shows the two advantages of using a flanged or cone versus a plain opening:
  - ➢ With a flange or cone, the hood entry loss is $0.25VP_d$ compared to $0.93VP_d$ for a plain opening.
  - ➢ The required airflow (Q) is lower with the flange or cone compared to the plain opening since less of the air is drawn from behind the hood.
- ➢ Figure 19–4 (metal polishing belt) also shows how steps to reduce turbulence will reduce hood entry loss. The term *take-off* refers to the connection between the hood and duct. With a tapered take-off (shown in the diagram), there is a transition section between the hood and duct to smooth out airflow patterns, resulting in a hood entry of $0.45VP_d$. With a straight take-off (not shown), there is no transition, resulting in more turbulence and a higher hood entry loss of $0.65VP_d$.
- ➢ Figure 19–5 (dip tank) shows the higher overall loss from a slotted hood. There is a loss of $1.78VP_s$ as the air moves through the slot into the plenum chamber. Then there is a loss of $0.25VP_d$ as the air enters the duct. The total loss is the sum of these two components. Note that the ACGIH *Manual* uses h_e for the total loss rather than $h_{e(\text{slot hood})}$ as in Equation (10).

The hood entry loss coefficients for many different hood shapes can be found in the ACGIH *Ventilation Manual*.

HOOD STATIC PRESSURE

For a hood to operate properly, the fan must generate enough suction or static pressure in the duct near the hood to overcome both the acceleration loss and the hood entry loss while drawing the correct amount of air into the hood. This amount of suction is called the *hood static pressure* and is easily measured using a water manometer (Figure 19–15).

For a hood without a slot, hood static pressure is calculated using the following equation:

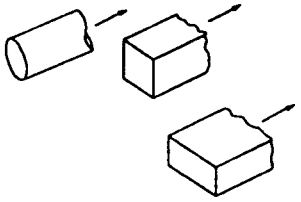
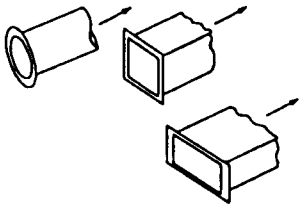
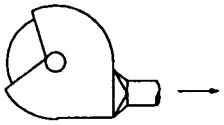
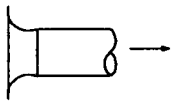
HOOD TYPE	DESCRIPTION	HOOD ENTRY LOSS (F_d)
	PLAIN OPENING	0.93
	FLANGED OPENING	0.49
	TYPICAL GRINDING HOOD	(STRAIGHT TAKEOFF) 0.65 (TAPERED TAKEOFF) 0.40
	BELL MOUTH INLET	0.04

Figure 19–14. Hood Entry Loss coefficients (F_d) for common hood types. For the grinding hood a "tapered take-off" means that there is a transition section between the hood and duct to smooth airflow, while a straight take-off (not shown) has no transition piece. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice*, 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

SP_h = Acceleration Loss + Hood Entry Loss
= (1.0 x duct velocity pressure) + (F_d x duct velocity pressure)
= 1.0 VP_d + F_d VP_d
$SP_h = (1.0 + F_d)\ VP_d$ (11)

where SP_h = hood static pressure (for a hood without a slot), inches of water
F_d = entry loss coefficient for hood
VP_d = duct velocity pressure, inches of water

For a slot hood, the loss caused by the slot must be added in:

$$SP_{h(slot)} = (1.0 + F_d)\ VP_d + F_s\ VP_s \quad (12)$$

where $SP_{h(slot)}$ = hood static pressure for slot hood, inches of water
F_s = slot entry loss coefficient
VP_s = slot velocity pressure, inches of water

Hood static pressure is important for the following two reasons:

➢ During system design, the SP_h can be calculated and represents the suction that is needed at the hood in order for the hood to function properly. Then the fan can be selected to move the required Q while generating sufficient static pressure so the required SP_h will be available at each hood. As a corollary, in an existing system if the fan cannot generate the required SP_h at a hood, then the hood will never function properly.

➢ Once a ventilation system is installed and operating properly, the hood static pressure can be measured and recorded. Periodic readings can be compared to the original value to determine if the suction available at the hood is still adequate to draw the required amount of air for proper hood operation.

Example: The barrel-filling hood in Figure 19–1 has a hood entry loss coefficient (F_d) of 0.25. Measurements show that the hood static pressure is 1.8 inches of water in the 4-inch diameter circular duct (area = 0.087 ft^2) at the hood. Estimate the airflow into this hood.

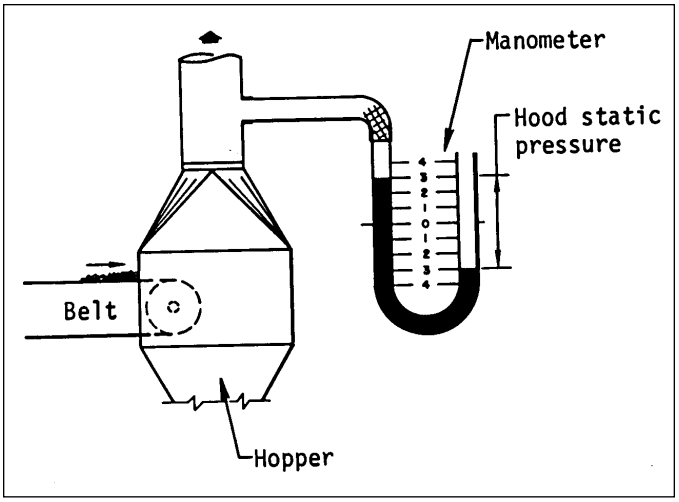


Figure 19–15. Hood Static Pressure, measured in the duct near the hood, represents the suction or potential energy available to draw air into the hood. (Source: McDermott, 2000).

Answer: A summary of the data is as follows:

$F_d = 0.25$
$SP_h = 1.8$ in. of water
Duct Diameter = 4 in. (area = 0.087 ft^2)

From Equation (11):
$SP_h = (1.0 + F_d)\ VP_d$
1.8 in. $H_20 = (1.0 + 0.25)\ VP_d$

Solving for VP_d:
$VP_d = 1.44$ in. of water

From Equation (9):
$V = 4{,}005 \sqrt{VP}$

$V = 4{,}005 \sqrt{1.44} = 4{,}806$ ft/min

From Equation (1):
$Q = V \times A$
$Q = 4{,}806$ ft/min $\times$ 0.087 ft^2
$Q = 418$ ft^3/min

PRESSURE LOSS IN THE DUCTS

Air flowing through the ductwork meets resistance in the form of friction and turbulence. Straight duct lengths result in friction loss, while elbows, junctions, air cleaners, and other features cause turbulence losses. These losses can be expressed as pressure drop since they represent pressure lost from the system that the fan must generate to make the system work properly.

Because of these losses, the following static pressure profile exists in an LEV system:

- ➢ Before the fan, the greatest suction value occurs at the fan inlet. Moving from the fan toward the hoods, the suction decreases because it is used to overcome friction and turbulence losses until, at the hood, just enough static pressure remains to overcome the acceleration and hood entry loss.
- ➢ After the fan, the greatest value of positive static pressure is at the fan outlet. The positive static pressure is used to overcome friction loss in any ducts and the stack as well as turbulence losses in any elbows. At the stack discharge, any remaining static pressure is used to discharge the air at a higher velocity to aid contaminant dispersion.

FAN PRESSURE

As described throughout this chapter, the fan generates pressure that causes the air to move through the system. In order to characterize fan performance, both the volumetric airflow (Q) and the pressure that the fan generates must be specified.

For LEV systems, this fan pressure is called *fan static pressure* (FSP). It is calculated from an equation used by fan manufacturers as part of a standard test of fan performance:

$$FSP = |SP_{inlet}| + |SP_{outlet}| - VP_{inlet} \qquad (13)$$

where FSP = fan static pressure, inches of water
SP = static pressure, inches of water
VP = velocity pressure, inches of water
$_{inlet,\ outlet}$ = fan inlet and outlet

FSP represents the net pressure that the fan adds to the system. The following points should be noted:

- ➢ The SP_{inlet} value is the total suction that the fan must generate to first accelerate room air up to duct velocity and then overcome all pressure losses before the fan.
- ➢ The SP_{outlet} value is the positive pressure required at the fan outlet to overcome the friction and other losses after the fan and finally discharge the air from the stack.
- ➢ The VP_{inlet} value is subtracted because it represents the energy in the moving air reaching the fan that was included in the SP_{inlet} value as the acceleration loss at the hood.

FAN LAWS DESCRIBE FAN PERFORMANCE

The following three equations, called *fan laws*, describe the relationship of volumetric airflow, fan static pressure, and brake horsepower to rotating speed for a specific fan:

- ➢ Changes in volumetric airflow (ft^3/min) vary directly with changes in fan speed. For example, for a given fan doubling the speed will double the volume output.

$$\frac{Q_1}{Q_2} = \frac{R_1}{R_2} \qquad (14)$$

where R = fan rotating speed, rev/min
Q = airflow, ft^3/min

➢ Changes in static pressure vary directly with the square of changes in fan speed.

$$\frac{FSP_1}{FSP_2} = \left(\frac{R_1}{R_2}\right)^2 \quad (15)$$

where FSP = fan static pressure, inches of water

➢ Changes in brake horsepower vary directly with the cube of changes in fan speed. *Brake horsepower* is the energy required to operate the fan, but does not include any drive loss between the fan and motor.

$$\frac{BHP_1}{BHP_2} = \left(\frac{R_1}{R_2}\right)^3 \quad (16)$$

where BHP = brake horsepower

Since all three of these fan laws act together, any change in fan speed to increase volume output also increases fan static pressure and brake horsepower.

This can be important since a common method of increasing Q in an existing system is to increase the fan rotating speed. This will increase volumetric airflow, but the brake horsepower, which represents electrical power consumption, increases as the third power of increases in fan rotating speed. For example, doubling the fan speed requires eight times more electrical power to run the fan (i.e., $2^3 = 8$). This could make increasing the fan speed a poor economic decision compared to replacing the existing fan with a larger model better suited for the application.

Fan manufacturers specify a maximum safe rotating speed for each fan to prevent mechanical failure. This speed cannot be exceeded when attempting to increase airflow in an LEV system.

Example: A fan is moving 4,000 ft^3/min of air. A tachometer reading shows the rotating speed to be 1,650 rev/min. Measurement of electrical consumption shows that the consumption is equivalent to 2.23 brake horsepower. Calculate the effect on rotating speed and horsepower of increasing the airflow to 5,000 ft^3/min.

Answer: Since rotating speed and volume output are proportional, use Equation (14) to find the new rotating speed:

$$\frac{Q_1}{Q_2} = \frac{R_1}{R_2}$$

where R = fan rotating speed, rev/min
Q = airflow, ft^3/min

$$\frac{4{,}000}{5{,}000} = \frac{1{,}650}{R_2}$$

R_2 = 2,063 rev/min

Calculate the new brake horsepower using Equation (16):

$$\frac{BHP_1}{BHP_2} = \left(\frac{R_1}{R_2}\right)^3$$

where BHP = brake horsepower

$$\frac{2.23}{BHP_2} = \left(\frac{1{,}650}{2{,}063}\right)^3$$

$$\frac{2.23}{BHP_2} = (0.80)^3 = 0.51$$

$$BHP_2 = \frac{2.23}{0.51}$$

BHP_2 = 4.4 horsepower

Whether or not the best solution lies in increasing the fan speed to achieve the desired performance is usually based on an economic evaluation. The cost of the added electrical power can be calculated over the projected life of the fan. For small increases in fan speed, the existing fan motor may be adequate but the fan manufacturer's literature will show whether a higher horsepower motor is needed. Also check the fan specifications to see whether the existing fan is safe at the required rotating speed.

LEV PERFORMANCE EVALUATION AND IMPROVEMENT

This section describes typical tests used to evaluate LEV system performance and, where applicable, simple steps to diagnose and resolve problems.

Smoke Tube Tests

Smoke tubes are glass tubes containing a chemical that produces a chemical fume (smoke) as room air is blown through the tube with a hand-operated bulb. They are useful for the following tests:

➢ evaluating the capture range of hoods
➢ identifying drafts and other factors that can interfere with hood performance
➢ demonstrating the capture distance of hoods to workers so they can position the hood or work item properly

Velocity Measurements

Several devices are available when a quantitative measurement of velocity is required. The main categories include:

➢ *Swinging vane velometer* contains a vane or paddle that moves according to the velocity of the air passing through the instrument. The paddle is connected mechanically to a meter that displays the velocity.
➢ *Thermo-anemometer* works on the principle that the resistance of a heated wire changes with temperature variations. Air moving over the heated wire element changes its tem-

perature depending on the air velocity. The anemometer is calibrated directly in feet per minute. Very high moisture levels may cause inaccurate readings if the moisture affects the change of resistance in the heated element.

- ➢ *Rotating vane anemometer* has a propeller-like velocity sensor connected either to a mechanical or electronic readout unit. This type of device comes in a variety of sizes; the smaller ones have a thin probe while larger units have a propeller that is several inches in diameter.
- ➢ *Pitot-tube devices* that determine the velocity pressure inside a duct and are connected to a liquid manometer or pressure sensor that displays output in either inches of water velocity pressure or directly in velocity. (A pitot tube is a special probe-like device that accurately measures static and total pressures inside a duct. The difference between total and static pressures equals velocity pressure.)

Typical applications for the first three devices are measuring capture velocity outside of capturing hoods, face velocity for enclosures, and slot velocities (Figure 19–16).

DUCT VELOCITY TRAVERSE

A traverse involves measuring the velocity at a number of points across the duct area since velocity distribution is not uniform within the duct. Typically, a pitot tube is used for the traverse, but any velometer with a narrow probe sensor may also be used. The measurement points are selected to divide the duct into enough zones of equal area according to the following guidelines:

- ➢ For round ducts two traverses at right angles should be made. For ducts 6 in. in diameter or smaller, make two 6-point traverses. For ducts 6 to 48 in., make at least two 10-point traverses. Above 48 in. or for smaller ducts where large velocity variations are suspected, make two 20-point traverses. The locations of the measuring points are selected to divide the duct into equal annular areas (Figure 19–17); they are *not* equidistant points along the duct diameter.
- ➢ For rectangular ducts, the cross section is divided into equal areas and a reading is taken at the center of each area. For accurate duct measurements, at least 16 readings should be taken, but the distance between measuring points should not exceed 6 in. Similarly, for large openings, such as laboratory hoods or paint spray booths, a series of velocity readings should be taken and averaged to estimate the average air velocity into the enclosure.

Regardless of duct shape, the best place to perform a traverse is at least 7.5 duct diameters downstream from any

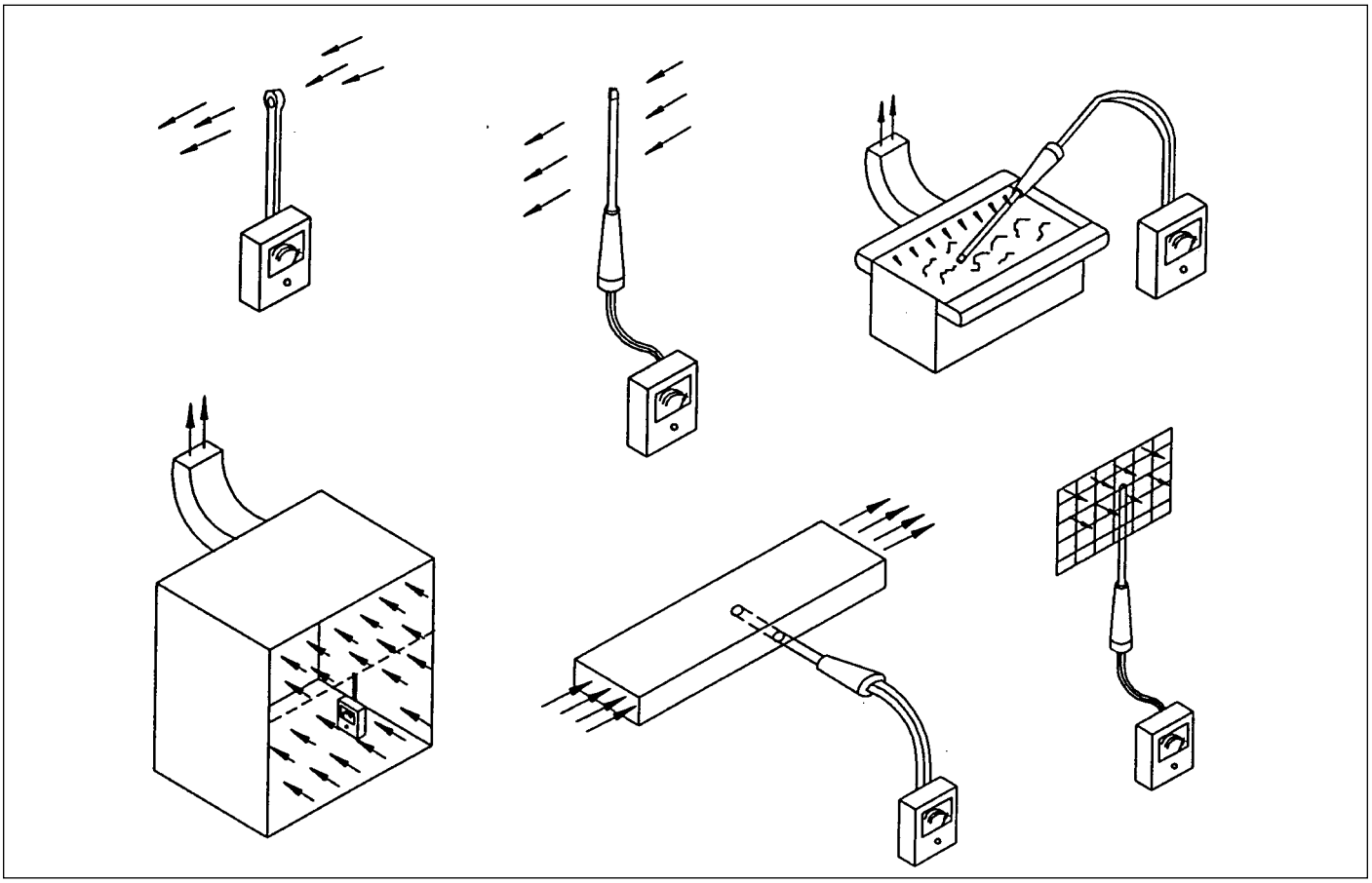


Figure 19–16. Typical applications for a velometer. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati. Reprinted with permission.)

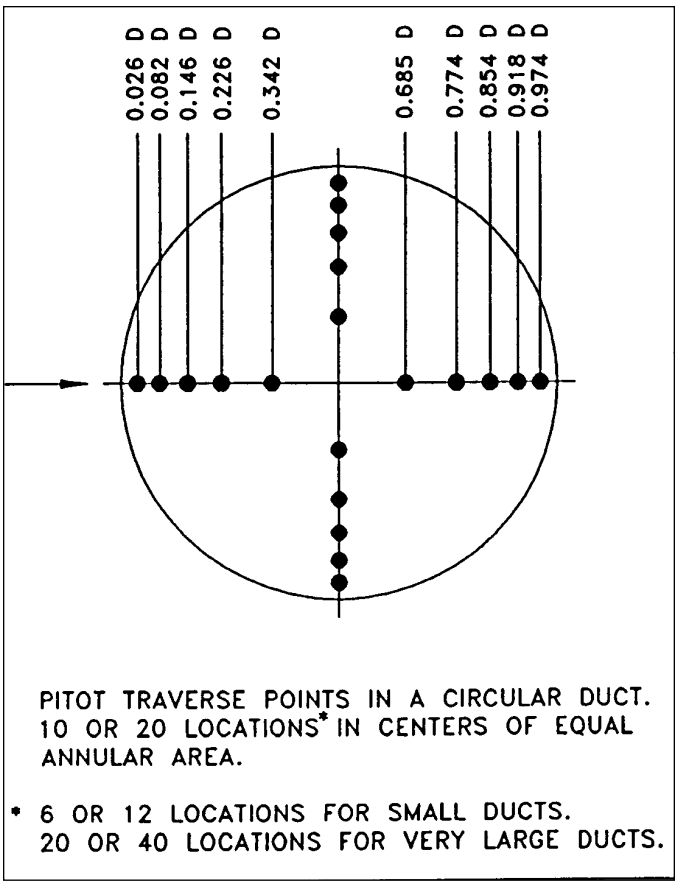


Figure 19–17. Measuring locations for a 10-point velocity traverse in a round duct. These points divide the duct into equal area annular rings.

major disturbance to smooth airflow, such as dampers or elbows. More specific guidelines for evaluating the validity of velocity traverse results are contained in the ACGIH *Ventilation Manual*.

Static Pressure Measurements

Periodic static pressure tests at the hoods and other locations in the LEV system are an excellent way to evaluate performance and diagnose problems. Since static pressure represents the potential energy available to move air in the system, changes in static pressure over time can indicate situations that degrade system performance. The greatest value of static pressure tests is from comparing current results to earlier readings. The LEV system should be balanced and hood velocities measured to assure adequate performance before instituting a static pressure test program.

To measure static pressure in a duct, a small diameter hole (1/16 to 1/8 in.) is drilled through the duct wall. It is important that no burrs around the drilled hole protrude into the flowing airstream; these can be removed by inserting a thin rod with a 90–degree bend into the hole and rotating it to smooth the edges. The holes should be at least 7.5 duct diameters downstream from any disturbance, such as an elbow, damper, or branch duct entry. If this is not possible, then four holes should be drilled 90 degrees apart around the duct and the measured static pressure values averaged. The end of a rubber tube attached to a U-tube manometer or other pressure sensor is pressed against the duct over the hole; the static pressure is read as inches of water (Figure 19–13). While a short length of metal tubing can be brazed onto the duct around the hole for the static pressure tube connection, simply holding the end of the rubber tubing against the duct will give an accurate reading. The hole does not have to be capped between tests if it is small enough. Permanent installation of a manometer or other pressure gauge is used for LEV systems where continuous measurements are needed,

HOOD STATIC PRESSURE

The principle of measuring hood static pressure is illustrated in Figure 19–15. The ideal location is about one duct diameter from the throat of a hood with a tapered transition into the duct, and about three duct diameters for plain openings or flanged hoods. This location will avoid measuring hood static pressure within the turbulent zone in the duct near the hood.

In setting up a hood static pressure test program, determine the airflow into hoods using velometer readings or a velocity traverse across the ducts. Adjust airflow to each hood until it meets design criteria, and then measure and record hood static pressure along with volumetric airflow (Q). If subsequent hood static pressure readings show a decrease at a hood, the change in flow rate can be calculated using the following equation:

$$\frac{Q}{Q_o} = \frac{\sqrt{SP_h}}{\sqrt{SP_{h(o)}}} \qquad (17)$$

where Q = current volumetric airflow rate, ft^3/min
Q_o = original volumetric airflow rate, ft^3/min
SP_h = current hood static pressure, inches of water
$SP_{h(o)}$ = original hood static pressure, inches of water

This technique is valid for all hood designs, including slot hoods.

Example: The hood static pressure at the conveyor belt discharge hood (i.e., the upper hood) in Figure 19–1 was 1.15 in. of water with airflow of 1,050 ft^3/min. Recent tests show the hood static pressure is now 0.87 in. of water. What is the current airflow into the hood?

Answer:

$$\frac{Q}{Q_o} = \frac{\sqrt{SP_h}}{\sqrt{SP_{h(o)}}}$$

$$Q = Q_o \frac{\sqrt{SP_h}}{\sqrt{SP_{h(o)}}}$$

$$Q = 1050 \text{ ft}^3/\text{min} \frac{\sqrt{0.87}}{\sqrt{1.15}} = 1050 \text{ ft}^3/\text{min} \left(\frac{0.93}{1.07}\right) = 914 \text{ ft}^3/\text{min}$$

The decline in airflow could be caused by a loose fan belt, plugged duct, or other problem.

OTHER STATIC PRESSURE TEST LOCATIONS

Static pressure tests at various other system locations are also valuable in measuring system performance and diagnosing malfunctions. Typical locations (in addition to hoods) to measure static pressure are at entries into main ducts, on each side of air cleaners, on each side of the fan, and at several points along long ducts. Initial and periodic static pressure readings should be recorded on a data sheet. Usually differences between readings at the same location that exceed 10 percent should be investigated to determine the reason for the change.

Here is an example of how static pressure tests can help diagnose ventilation system problems. A ventilation system (Figure 19–18) consists of six hoods and branch ducts, a main duct, an air cleaner, and a fan. Over several years the following problems were identified:

- ➢ The hood static pressures are low in all hoods (Figure 19–18a). Further tests show that static pressure on the hood side of the air cleaner is low, while it is higher than usual between the air cleaner and fan. These readings indicate that the air cleaner is causing too much resistance and should be cleaned to restore proper performance.
- ➢ The static pressure readings on both sides of the air cleaner are higher than usual (Figure 19–18b) while the hood static pressure readings for all hoods are low. This indicates that the main duct is partially plugged just before the air cleaner.
- ➢ The hood static pressure readings are low (Figure 19–18c) as is the static pressure on both sides of the air cleaner. This indicates that the fan is not working properly, the discharge stack is plugged, or there is a loose duct joint between the air cleaner and fan.
- ➢ All static pressure readings are normal except the value at one hood, which is too low (Figure 19–18d). This indicates that the branch duct is plugged between the test point and the main duct.
- ➢ All static pressure readings are near normal except one

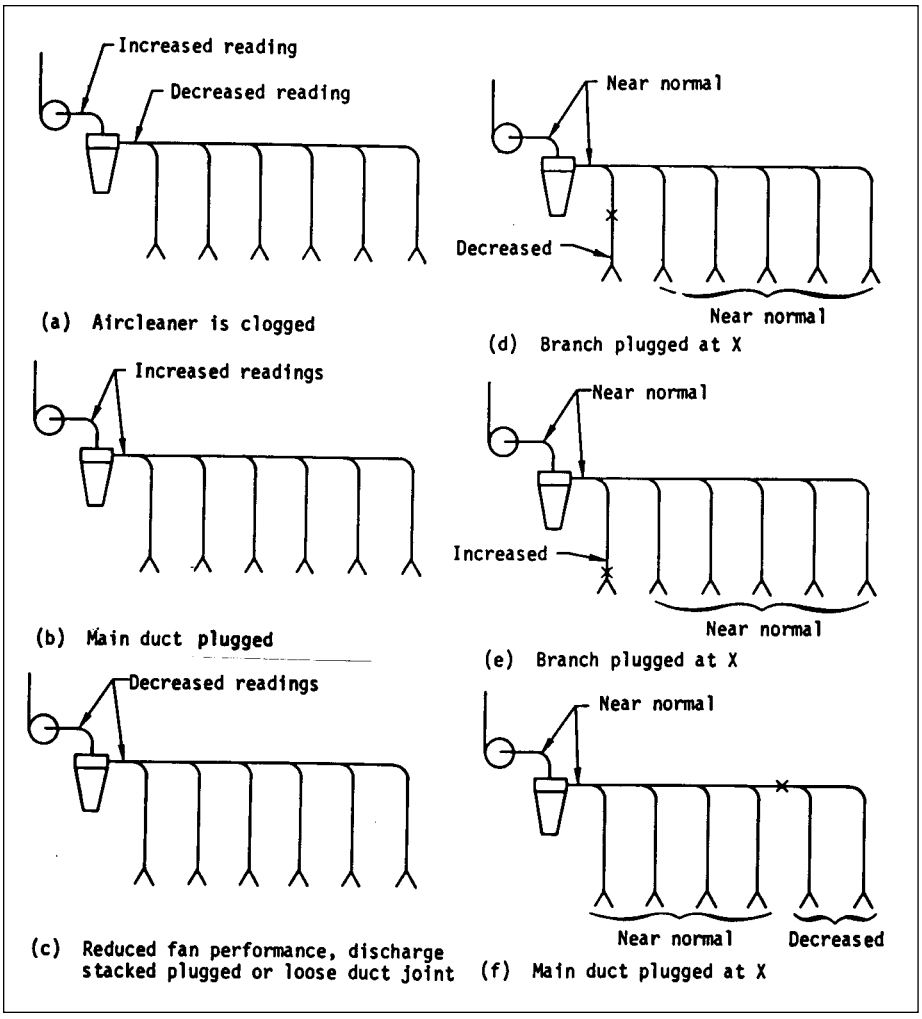


Figure 19–18. LEV system problems diagnosed by comparing static pressure reading with earlier tests. (Source: McDermott, 2000.)

hood static pressure reading, which is increased (Figure 19–18e). This means that a blockage exists between the hood opening and the hood static pressure test point.

➢ All static pressure readings are near normal except the hood static pressure readings in two adjacent hoods, which are decreased (Figure 19–18f). This indicates that the main duct is plugged near the two hoods with lower hood static pressure values.

All of these difficulties were quickly solved once the source of trouble was recognized. Note that where a blockage caused a higher static pressure reading on the fan side of the blockage, this occurred because the blockage prevented the suction (static pressure) from being converted into velocity pressure.

Static pressure tests in a system that once operated properly can help to identify the following fan problems:

➢ loose fan belt or another drive problem

➢ material deposited on blades (especially with forward-inclined blade fan) or blade erosion/corrosion

➢ centrifugal fan motor wired incorrectly and therefore rotating backward. (Larger fan motors are wired in a three-phase configuration, and if the electrical supply wires are connected to the wrong terminals, the motor rotates in the wrong direction. The result is that the fan will be excessively noisy and will move less air than expected. However, an axial flow fan rotating backward will move air in the wrong direction.)

SUMMARY

Local exhaust ventilation (LEV) systems are an important technique for controlling employee exposures to airborne contaminants. A sound understanding of system components and the airflow and pressure principles that govern system operation will help the safety and industrial hygiene practitioner apply LEV properly.

A Bibliography for this chapter appears at the end of Chapter 20, Dilution Ventilation for Industrial Workplaces.

Chapter 20

Dilution Ventilation of Industrial Workplaces

revised by Henry J. McDermott, CIH, PE

This chapter describes the principles and practices for using dilution ventilation to remove airborne contaminants from industrial work areas such as shops and factories, and for enclosed or confined spaces. General ventilation to control indoor air quality in offices and similar settings is covered in Chapter 21, General Ventilation of Nonindustrial Workplaces.

INTRODUCTION

As described in Chapter 19, Local Exhaust Ventilation, *local exhaust ventilation* and *dilution ventilation* are both used to control the concentration of air contaminants in the workplace.

Dilution occurs when contaminants released into the workroom mix with air flowing through the room (Figure 20–1). Either natural or mechanically induced air movement can be used to dilute contaminants. Dilution ventilation is sometimes called *general* ventilation. However, the overall heating, ventilating, and air conditioning (HVAC) system in a building is often referred to as the general ventilation system. To avoid confusion, the term *dilution* is used for contaminant control systems in this chapter.

It is important to realize that with dilution ventilation the contaminants actually disperse into the workroom air and then are gradually removed. The dilution airflow is not capable of generating air currents that "sweep" the contaminants directly from the source to the wall or roof mounted exhaust fan. Some of the dilution air passes through the zone of contaminant release and dilutes the contaminants to a lower concentration. The dilution continues as the material moves farther from the process until the contaminated air is removed by the exhaust fan. Depending on the location of the air inlet and exhaust fan, and the total airflow through the room, a considerable time period may elapse after the process stops before all contaminants are removed from the room.

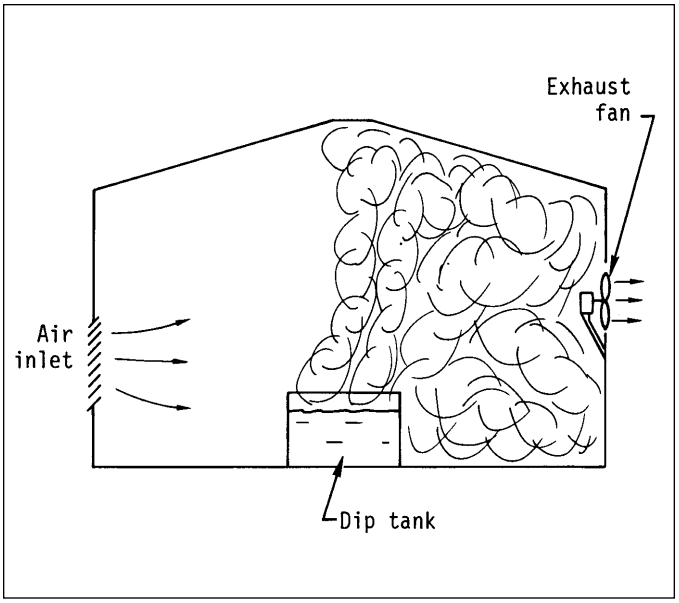


Figure 20–1. Dilution ventilation gradually removes contaminants dispersed in the workroom air.

Dilution ventilation is used in situations meeting these criteria:

- ➢ Small quantities of contaminants released into the workroom at fairly uniform rates.
- ➢ Sufficient distance from the source to the worker (or source of ignition for fire/explosion hazards) to the contaminant source to allow for dilution to safe levels.
- ➢ Contaminants of relatively low toxicity or fire hazard so that no major problems will result from unanticipated minor employee exposure or concentration exceedances.
- ➢ No air-cleaning device needed to collect contaminants before the exhaust air is discharged into the community environment.
- ➢ No corrosion or other problems from the diluted contaminants in the workroom air.

The major disadvantage of dilution ventilation is that the inherent uncertainties that exist in many of the design parameters require that large safety factors be applied to assure that exposures are controlled. This is described in detail later in this chapter, but the uncertainties often result in large volumes of air being needed, and may make dilution ventilation less cost-effective than local exhaust ventilation or another exposure control technique.

Dilution ventilation can also be used to control hot temperatures from industrial operations or other sources. Heat can be a health hazard in extreme exposures, and so the proper design of dilution systems to control this hazard is important. Heat load occurs both from the radiant heat and convective heat emitted by hot sources (called *sensible* heat), and from the heat released to the room from condensing steam or water vapor (called *latent* heat). A thorough explanation of the data needed to calculate the required airflow to control heat exposures is beyond the scope of this chapter; refer to the ACGIH *Manual* for details (ACGIH, 1998).

DILUTION VENTILATION SYSTEMS

Natural Ventilation

Natural ventilation is air movement within a work area due to wind, temperature differences between the exterior and interior of a building, or other factors where no mechanical air mover is used.

Even moderate winds can move large volumes of air through open doors or windows. For example, a 15 mph wind blowing directly at a window with an open area of 36 ft^2 can move 25,000 ft^3/min or more through the window if the air can freely escape from the building through a doorway or other large opening. Unfortunately the wind speed and direction are usually not reliable, and so unless production can be scheduled to coincide with favorable winds, this would not be an adequate exposure control technique. In many regions this large dilution air volume must be heated in winter. This is an important cost factor that can over-ride the apparent savings of a system with no mechanical air mover.

Air movement due to temperature differences may be more useful than motion caused by wind. Hot processes heat the surrounding air and the rising column of warm air will carry contaminants upward to roof vents. As long as a worker does not have to lean over the heated process and breathe the rising contaminated air, this type of natural ventilation may be adequate. A good supply of replacement air for the building is needed, especially during winter when doors and windows may be closed to minimize drafts.

Mechanical Ventilation

Mechanical systems range from simple wall-mounted propeller fans or roof-mounted mechanical ventilators to complex designs with engineered supply and exhaust systems. Propeller fans can provide a constant, reliable flow of air, but a major characteristic is that they are efficient air movers only as long as an adequate supply of replacement or makeup air can *readily* enter the area being exhausted (as described in Chapter 19, Local Exhaust Ventilation). Thus even a simple dilution system may require a complex make-up air system with separate air supply fans and ducts. This increases the dilution fan effectiveness but the total installed and operating costs can approach the cost of a local exhaust system.

DILUTION SYSTEM DESIGN CONSIDERATIONS

Safety Factors

The equations for calculating the dilution airflow rate required for either health protection or fire/explosion prevention are straightforward, but there are some limitations that must be understood. The equations are based on the concept that the contaminant is released at a certain rate (ft^3/min), and so the ventilation system must move the correct airflow (ft^3/min) to dilute this generated rate of contaminant to an

acceptable level. In order to apply these equations prudently, it is important to understand two factors:

- ➢ The "theoretical" equations assume that complete mixing occurs in the room. This means that all of the dilution air helps to dilute the contaminant to acceptable levels before anyone breathes the air (or, for fire/explosion prevention, before the vapors reach a source of ignition). Complete mixing rarely occurs in real world situations.
- ➢ These equations will yield the airflow needed to keep the airborne level precisely at the "target concentration" used in the dilution equations. If the OSHA *Permissible Exposure Limit* or ACGIH *Threshold Limit Value (TLV®)* is selected as the target concentration, the "theoretical" equations will yield the required airflow to keep airborne levels exactly at that level. An adequate safety factor should be applied to keep concentrations well below the acceptable exposure level.

The dilution equations discussed below adjust for these considerations. The airflow equations for systems designed to protect heath (as contrasted with fire/explosion prevention) contain a *K factor* that increases the theoretical quantity needed to dilute the contaminants. The equations for fire/explosion prevention use a S_f *factor* that performs the equivalent function. In both cases it is the designer's responsibility to choose the appropriate value to account for these factors:

- ➢ The design and layout of the exhaust fan and any air supply system (in relation to the work operation) that impacts how much of the airflow actually works to dilute the con-

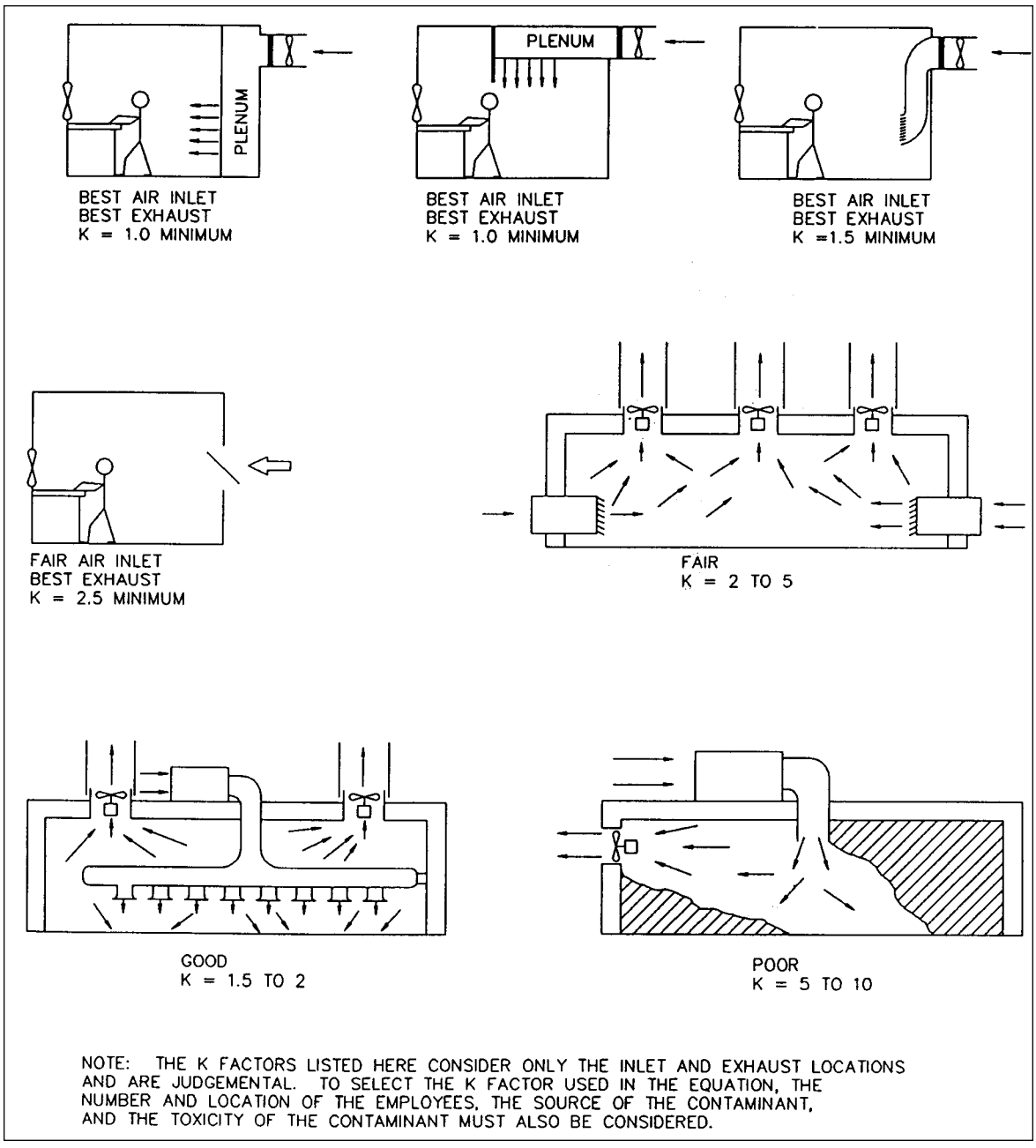


Figure 20–2. K is a safety factor that adjusts the calculated dilution airflow for various situations including nonideal air distribution in the workplace. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati, Ohio. Reprinted with permission.)

taminants before workers breathe the air or the contaminated air reaches a source of ignition (Figure 20–2).

- ➢ Any significant unknown information or parameters about a new process or operation that could impact the amount of contaminant released or whether the release is constant or irregular.
- ➢ Any additional "safety factor" needed to account for circumstances such as nonroutine work patterns that could bring workers closer than expected to the contaminant source, or other conditions where an added safety factor is warranted.

Even if the appropriate considerations are applied when choosing the K factor, there is still a risk that changes in the chemicals used or reductions in the allowable exposure limits for the original chemicals will render the system unacceptable. For example, if the Threshold Limit Value® for a chemical were reduced by 50 percent, the calculated dilution airflow would have to be doubled to maintain the same ratio of actual concentration to TLV®. There is less risk of this occurring with local exhaust ventilation (LEV) because the design assumption for LEV systems is to prevent contaminant escape to the work environment rather than diluting them to acceptable levels once they are released.

Dilution Ventilation System Layout

Dilution systems work best when the air inlet and exhaust fan are located so that as much air as possible flows through the zone of contaminant release. Only the air that passes through the area where contaminants are released is available for immediate dilution of contaminants to safe levels. For the dilution air to be effective at all, it must dilute the contaminants before they reach an employee's breathing zone. As illustrated in Figure 20–2, system layout has a direct impact on the K factor used in the dilution equations.

The air inlet and exhaust fans should be arranged so that air movement is from cleaner to dirtier areas. Locate the processes or locate the fan so that the units that release contaminants are as close as possible to the fan. Also eliminate or provide separate exhaust for areas where contaminants may accumulate and defeat the dilution effect of the airflow from the overall system.

CALCULATING DILUTION AIRFLOW FOR HEALTH PROTECTION

When a chemical is first released at a constant rate into a ventilated workroom, there is a gradual concentration buildup until a steady-state condition is reached. At this concentration, the emission rate and removal rate are in equilibrium so the concentration remains about constant. After chemical release stops, there is a gradual purging of the workplace air until the concentration reaches zero (Figure 20–3).

Dilution Ventilation for Health: Steady-State

The amount of dilution airflow required depends on the physical properties of the contaminant (molecular weight and specific gravity [compared to water]), rate of contaminant release, the target airborne concentration, and the overall safety factor (K) as described above.

The equation for calculating the steady-state dilution airflow rate for toxic or irritating contaminants is:

$$Q = \frac{403 \times \text{sp gr} \times W \times K \times 1{,}000{,}000}{M \times L} \qquad (1)$$

where Q = dilution airflow, ft^3/min
sp gr = specific gravity of liquid (water = 1.0)
W = amount of liquid used (evaporated), pints/minute
M = molecular weight of contaminant
L = target airborne concentration of contaminant to be maintained in the work environment (usually based on OSHA standards or TLV list with an appropriate safety factor), ppm
K = dimensionless safety factor to increase the calculated airflow rate over the minimum, in order to take nonideal conditions into account. K normally ranges from 3 to 10 depending on the overall effectiveness of the ventilation system, and uniformity of contaminant evolution. A higher K value is associated with poor airflow conditions and other unknown conditions or circumstances that could increase exposures to workers (see Figure 20–2).

Example: A cleaning operation in an open-bay work area uses methyl ethyl ketone (2-butanone) at the rate of 2 pints/h. The general air distribution is good but the layout of the workroom prevents some of the dilution air from passing directly through the zone of contaminant evolution at the workbench—assume a value of 5 for "K." Calculate the dilution airflow requirement to maintain the airborne concentration at 50 ppm.

Answer: The amount of chemical released is 2 pints/h, or 0.033 pints/min. The specific gravity of methyl ethyl ketone is 0.81 and its molecular weight is 72 (NIOSH, 1994). Applying Equation 1:

$$Q = \frac{403 \times \text{sp gr} \times W \times K \times 1{,}000{,}000}{M \times L}$$

$$Q = \frac{403 \times 0.81 \times 0.033 \text{ pints/min} \times 5 \times 1{,}000{,}000}{72 \times 50}$$

$$Q = 14{,}961 \text{ ft}^3\text{/min}$$

Dilution Ventilation for Health: Purging

The purging rate equation can estimate how long it will take the fan to remove the contaminated air from the work environment after the release or generation of contaminant ceases. This is when all residual liquid has been cleaned up or has evaporated into the air, which is when the release of contaminant ceases.

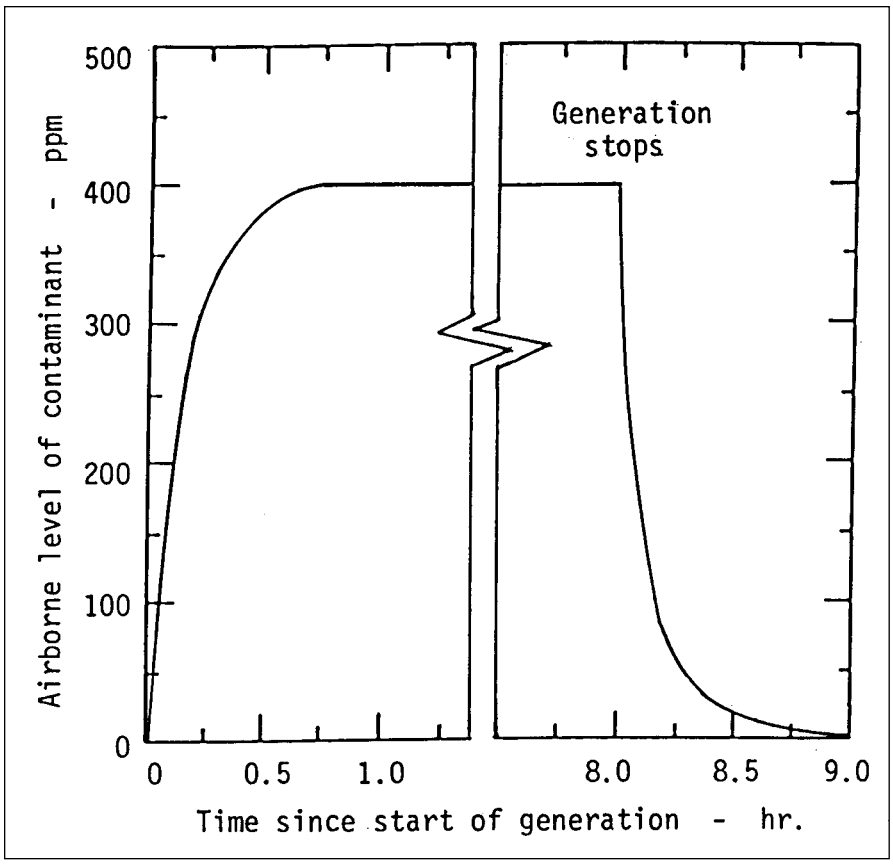


Figure 20–3. Concentration versus time for a workplace ventilated by a dilution system. The overall goal is to maintain the steady-state airborne level at or below the target concentration.

Since these calculations are more complex than Equation 1, it is easier to define a new term that can be used in the purging equation:

$$Q' = \frac{Q}{K} \qquad (2)$$

where Q' = effective ventilation airflow (i.e.,the airflow that dilutes the contaminants before they reach the workers' breathing zone), ft^3/min
Q = actual ventilation airflow, ft^3/min
K = dimensionless safety factor that accounts for any airflow that is not effective in diluting contaminants before they reach an employee's breathing zone (see complete definition under Equation 1)

When further release of generation of contaminant has ceased, the concentration as a function of time can be calculated from:

$$C_t = C_{original}\ [e^{(-Q't/Vr)}] \qquad (3)$$

where C_t = concentration at any time t, ppm
$C_{original}$ = concentration when generation ceased, ppm
t = time since contaminant release ceased, minutes
V_r = room volume, ft^3

Because of the mathematical relationship involved, C_t will never reach zero. However, the time to reach very low concentrations (approaching zero) can be estimated. The right portion of Figure 20–3 illustrates concentration as a function of time during purging.

Equation 3 is particularly useful in estimating the airborne concentration versus elapsed time following a spill or release of a chemical in a work area where the dilution ventilation rate is known.

Example: There was a spill of methyl ethyl ketone in the work area described in the previous example. The area was evacuated immediately, and a properly equipped emergency squad responded to clean up the spilled liquid. The airborne levels measured with a direct reading instrument showed 4,000 ppm after the clean-up was competed. How long will it take for the airborne level to return to the target concentration of 50 ppm? The dimensions of the work area are 25 ft x 30 ft x 12 ft high.

Answer: Applying Equation 2:

$$Q' = \frac{Q}{K}$$

$$Q' = \frac{14{,}961\ ft^3/min}{5} = 2{,}992\ ft^3/min$$

Applying Equation 3 with V_r = 25 x 30 x 12 = 9,000 ft^3:

$$C_t = C_{original}\ [e^{(-Q't/Vr)}]$$

$$50 \text{ ppm} = 4{,}000 \text{ ppm } [e^{[(-2992\ t)/9000]}]$$

$$50 = 4{,}000\ [e^{(-0.33t)}]$$

$$\frac{50}{4{,}000} = [e^{(-0.33t)}]$$

$$0.0125 = [e^{(-0.33t)}]$$

$$\ln (0.0125) = \ln [e^{(-0.33t)}]$$

$$-4.38 = -0.33t$$

$$t = 13.3 \text{ minutes}$$

Table 20–A shows the use of Equation 3 to estimate the approximate elapsed time to reach 10 percent and one percent of the original concentration based on the ratio of Q' to room volume:

$$\text{Effective Air Exchange Rate (air changes/min)} = \frac{Q'}{V_r} \quad (4)$$

Example: For the previous example, estimate the time until the concentration reaches one percent of the original concentration (i.e., 40 ppm).

Answer: Applying Equation 4:

$$\text{Effective Air Exchange Rate} = \frac{Q'}{V_r} = \frac{2{,}992 \text{ ft}^3/\text{min}}{9{,}000 \text{ ft}^3}$$

$$= 0.33 \text{ air changes/min}$$

From Table 20–A, the closest listed value of Effective Air Exchange Rate is 0.35. With this rate it will take approximately 13 minutes to reach 40 ppm, which is one percent of the original concentration. This value is very close to the time calculated in the example above; the difference is due to using the closest Effective Air Exchange Rate in the table rather than the actual value.

Dilution Airflow Design Data

As an option to using Equation 1, the ACGIH *Manual* contains airflow recommendations for some applications such as general welding (Table 20–B), and use of lift trucks powered by internal combustion engines inside buildings.

For example, a dilution airflow of 5,000 ft^3/min for each propane-fueled lift truck and 8,000 ft^3/min for each gasoline-fueled lift truck is recommended under the following conditions (ACGIH, 1998):

- ➢ A regular maintenance program incorporating final engine tuning through carbon monoxide analysis of exhaust gas must be provided, with CO concentrations no higher than 1 percent for propane-fueled trucks and 2 percent for gasoline-fueled trucks.
- ➢ Periods of lift truck operation do not exceed 50 percent of the working day.
- ➢ A reasonably good distribution of airflow must be provided.
- ➢ The volume of space must be at least 150,000 ft^3/lift truck.
- ➢ The truck must be powered by an engine of less than 60 hp.

This type of design information is especially helpful for new facilities where no ambient contaminant measurements can be conducted prior to system design.

CALCULATING DILUTION AIRFLOW FOR FIRE AND EXPLOSION PREVENTION

Dilution ventilation is used to reduce concentrations of flammable or explosive gases, vapors, or dust to safe levels well below

Table 20–A. *Time to Purge Workroom Based on Effective Air Exchange Rate*

Effective Air Exchange Rate,[a] Air changes/min	*Approximate time (minutes) to reach stated percent of original concentration after contaminant generation ceases*	
	10 percent of C_o	1 percent of C_o
0.02	115	230
0.05	46	92
0.10	23	46
0.15	15	30
0.20	12	24
0.25	9	18
0.30	8	15
0.35	7	13
0.40	6	12
0.45	5	10
0.50	5	9
0.60	4	8

[a] See definition in text.

Table 20–B. ***Dilution Airflow for Welding[a]***

Welding Rod diameter, inches	*Airflow, ft³/min per welder*
3/32	1000
3/16	1500
1/4	3500
3/8	4500
or	
A. For open areas, where welding fume can rise away from the breathing zone: ft^3/min required = 800 x lb/hour rod used.	
B. For enclosed areas or positions where fume does not readily escape breathing zone: ft^3/min required = 1600 x lb/hour rod used.	

[a] Where Local Exhaust Ventilation cannot be used.

their lower explosive limit (LEL). The dilution must occur before the contaminated air reaches any source of ignition. The accumulation of flammable or explosive mixtures in basements, pits, and other locations also must be considered in addition to diluting vapors in the general work area. The equation for calculating dilution airflow for flammable or explosive gases or vapors is:

$$Q = \frac{403 \times \text{sp gr} \times W \times S_f \times 100}{M \times LEL \times B} \qquad (5)$$

where Q = dilution airflow, ft^3/min
sp gr = specific gravity of liquid (water = 1.0)
W = amount of flammable liquid used or released, pints/min
S_f = dimensionless safety factor that depends on the percentage of LEL acceptable for safe conditions. For some applications the concentration should not exceed 25 percent of the LEL so S_f = 4 (i.e., 100 ÷ 25 = 4); for other situations S_f values of 10 or higher may be needed.
M = molecular weight of contaminant
LEL = lower explosive limit of contaminant, percent
B = constant reflecting that the LEL decreases at elevated temperatures. B = 1 for temperatures up to 250 F, B = 0.7 for temperatures above 250 F.

Equation 5 is based on the assumption that 100 percent of the dilution air is effective in diluting the contaminant before the contaminated air reaches a source of ignition. If this is not the case, the calculated Q must be multiplied by an additional safety factor.

Some operations release peak amounts of contaminants over a short time period. For example, drying ovens evaporate solvents rapidly during the first few minutes after objects are placed in the oven. In these cases the value of W should reflect the peak emission rate rather than the average rate.

When both employee exposure and fire/explosion prevention are considered for the same operation, the dilution flow rate calculated using Equation 1 almost always governs because the allowable airborne levels for breathing are significantly lower than the LELs for almost all, if not all, substances.

Example: As part of a laboratory analytical test, one pint of n-hexane is evaporated per hour in a small evaporation chamber. How much airflow is needed through the chamber to keep the concentration at 5 percent of the LEL?

Answer: Since one pint is evaporated per hour:

$$W = \frac{1 \text{ pint}}{h} \quad \frac{1(h)}{(60 \text{ min})} = 0.017 \text{ pints/min}$$

The specific gravity of n-hexane is 0.66, the molecular weight is 86, and the LEL is 1.1 percent (NIOSH, 1994). Since the temperature is less than 250 F, B = 1. To maintain the concentration at 20 percent of the LEL, S_f = 20 (i.e., 100 ÷ 5 = 20). Applying Equation 5:

$$Q = \frac{403 \times \text{sp gr} \times W \times S_f \times 100}{M \times LEL \times B}$$

$$Q = \frac{403 \times 0.66 \times 0.017 \times 20 \times 100}{86 \times 1.1 \times 1}$$

$$Q = 95.6 \text{ ft}^3\text{/min}$$

Air Density Adjustments Due to HighTemperatures

Equations 1 through 5 assume that the dilution air has standard density of 0.075 lb/ft^3. This is the density of air at 70 F, 29.92 in. of mercury atmospheric pressure, and 50 percent relative humidity. Factors that affect density are temperature, altitude, and humidity. Density correction calculations are explained in Chapter 19, Local Exhaust Ventilation. For dilution systems the most common factor is high temperature within drying ovens or similar enclosures. Density adjustments for high temperatures can be calculated from:

$$Q_{actual} = Q_{calculated} \left(\frac{460 \text{ F} + T}{(530 \text{ F})} \right) \qquad (6)$$

where Q_{actual} = dilution airflow at actual temperature, ft^3/min
$Q_{calculated}$ = dilution airflow calculated from Equations (1) or (5), ft^3/min
T = actual dilution air temperature, F

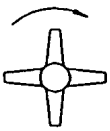
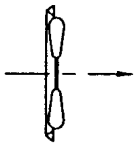
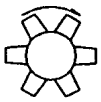
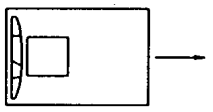
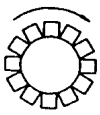
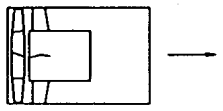
TYPE		IMPELLER DESIGN	HOUSING DESIGN
AXIAL FANS	PROPELLER	 Efficiency is low. Impellers are usually of inexpensive construction and limited to low pressure applications. Impeller is of 2 or more blades, usually of single thickness attached to relatively small hub. Energy transfer is primarily in form of velocity pressure.	 Simple circular ring, orifice plate, or venturi design. Design can substantially influence performance and optimum design is reasonably close to the blade tips and forms a smooth inlet flow contour to the wheel.
	TUBEAXIAL	 Somewhat more efficient than propeller fan design and is capable of developing a more useful static pressure range. Number of blades usually from 4 to 8 and hub is usually less than 50% of fan tip diameter. Blades can be of airfoil or single thickness cross section.	 Cylindrical tube formed so that the running clearance between the wheel tip and tube is close. This results in significant improvement over propeller fans.
	VANEAXIAL	 Good design of blades permits medium- to high-pressure capability at good efficiency. The most efficient fans of this type have airfoil blades. Blades are fixed or adjustable pitch types and hub is usually greater than 50% of fan tip diameter.	 Cylindrical tube closely fitted to the outer diameter of blade tips and fitted with a set of guide vanes. Upstream or downstream from the impeller, guide vanes convert the rotary energy imparted to the air and increase pressure and efficiency of fan.

Figure 20–4. Typical fans used for dilution ventilation. (Source: From American Conference of Governmental Industrial Hygienists (ACGIH®). *Industrial Ventilation: A Manual of Recommended Practice,* 23rd ed. Copyright 1998, Cincinnati, Ohio. Reprinted with permission.)

FANS FOR DILUTION VENTILATION

As explained in Chapter 19, Local Exhaust Ventilation, there are two main categories of fans: *centrifugal fans* and *axial flow fans.* Centrifugal fans, most often used in LEV systems, were described in the previous chapter. Dilution systems may use either type of fan, but the simple dilution systems described in this chapter would typically be a good application for an axial flow fan.

With axial fans the air travels parallel to the fan shaft and leaves the fan in the same direction as it entered. A screw or propeller action produces airflow. There are three different types of axial fans (Figure 20–4):

Propeller fans move air where there is no resistance to airflow and there is a ready source of make-up air. They are suitable for use as exhaust fans through a wall or similar application. They are not used with ducts because they do not produce pressure (either positive pressure or suction). Of all the axial fans, the propeller fan exhibits the most severe drop in airflow as resistance increases.

Tubeaxial fans are special propeller fans mounted inside a short duct section. The fan blades are specially shaped to enable the fan to move air against low resistance. This type of fan can be used as an exhaust fan, and is often used with flexible ducts for temporary dilution set-ups. It is also used for some LEV applications such as paint spray booths.

Vaneaxial fans are similar to tubeaxial fans but have vanes mounted in the duct to convert spinning air motion into higher static pressure and to straighten out the moving air. This type of fan is commonly used in HVAC systems. For dilution systems it could be used as an exhaust fan or for the make-up air supply fan for a complex system. They are usually noisier than other axial fan designs.

VENTILATION OF NORMALLY UNOCCUPIED ENCLOSED SPACES

Dilution is often used to ventilate workspaces such as tanks and utility vaults that are usually unoccupied but occasionally require workers to enter for inspection, cleaning, maintenance or other tasks. Effective use of dilution in these situations require careful application of the principles described so far in this chapter, plus additional concepts unique to the enclosed spaces.

Work in confined or enclosed spaces presents special hazards including oxygen deficiency, toxic contaminants, risk of engulfment by solid materials, and the risk of being trapped by small passageways. Working safely in these locations where hazards either exist or might develop requires extraordinary care. A safety plan for work in these locations includes features such as preventing unauthorized entry, identifying and controlling the

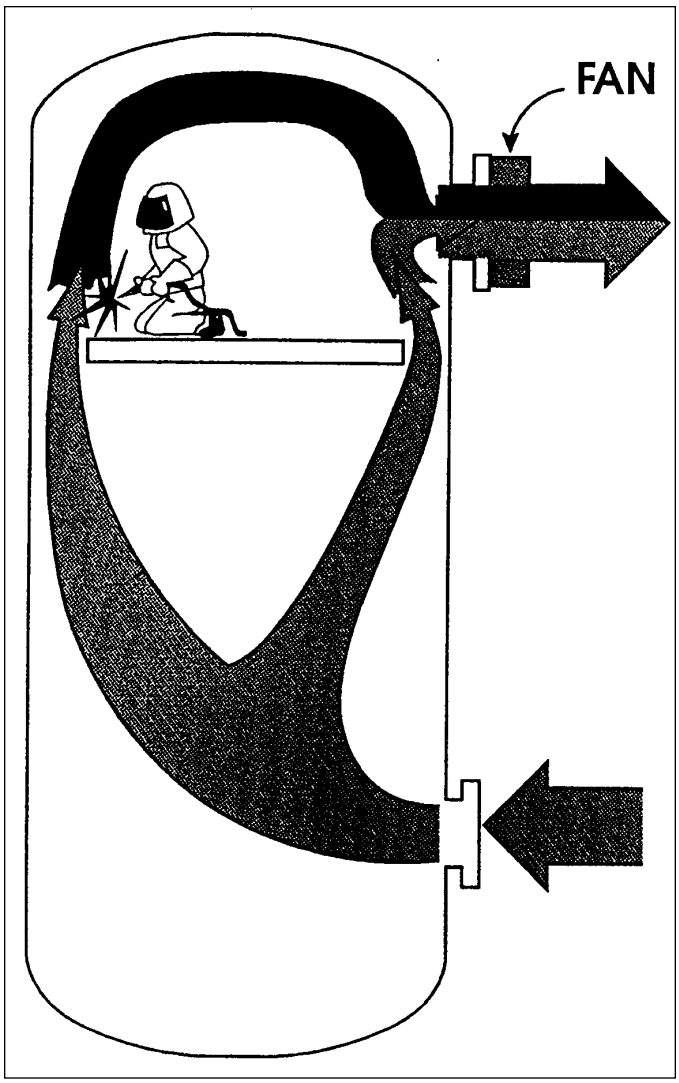


Figure 20–5. The dilution ventilation must work with natural air movement such as the conv ective rise due to solar heat load on this process vessel. (Courtesy ExxonMobil Corporation.)

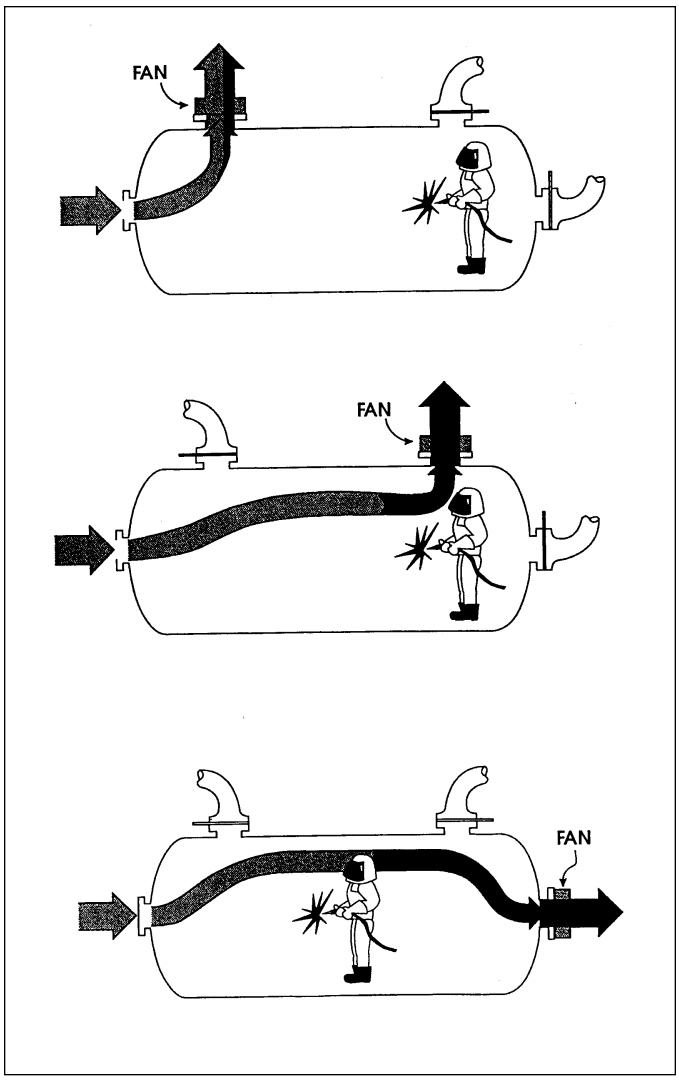


Figure 20–6. Short circuiting (top) reduces the effectiveness of dilution ventilation. Relocating the fan and make-up air entry ports can help to solve the problem. (Courtesy ExxonMobil Corporation.)

potential hazards, performing air monitoring, providing ventilation, providing rescue equipment and personnel, and training employees. The work may be subject to specific regulations such as the OSHA "Permit-Required Confined Spaces" standard. (U.S. OSHA: 29 *CFR* 1910.146). Other standards may cover specific work tasks such as welding, and require local exhaust ventilation or specific respiratory protection depending on the materials involved. *The requirements in all applicable legal and consensus standards must be understood before beginning any work in these locations.*

Effective use of dilution should follow these principles:

➢ In many enclosed spaces there is a natural air movement due to the solar load or other factors. For example, in a large tank or process vessel located outdoors there is often a *chimney effect* from the sun's heat that causes the air to rise (Figure 20–5).

Underground utility vaults may have a natural air movement due to thermal load on an attached building or other structure. In some spaces the air direction may change over the course of a day due to warming and cooling cycles. Dilution ventilation should be arranged to take advantage of the natural movement. Mechanical dilution fans may not be strong enough to overcome natural air movement if the set-up requires the fan to work against the natural forces such as convection.

➢ Air distribution inside these spaces must be managed. *Short circuiting* can occur if the air moves from the inlet to the exhaust fan without diluting contaminants where employees are working. Temporary scaffolding or other internal features may impede good airflow. It may be necessary to block off some air inlets or take other steps to assure good air distribution (Figure 20–6).

In many applications good air distribution is easier to achieve if fresh air is blown into the space using a flexible duct arrangement rather than using the fan to exhaust the space. The air can be discharged into the area where people are working, and will flow out available openings (Figure 20–7).With this arrangement, care is needed to assure that the high velocity air discharge in the workspace does not stir up dust and cause an eye hazard.

➢ Another type of short circuiting can occur if the exhaust fan or duct is not sealed to the workspace opening. In this case outside air is pulled back through the fan rather than air from the interior of the closed space (Figure 20–8). Bolts and clamps to hold the fan in place can solve this problem, with plywood adapter plates between the fan and workspace opening where needed.

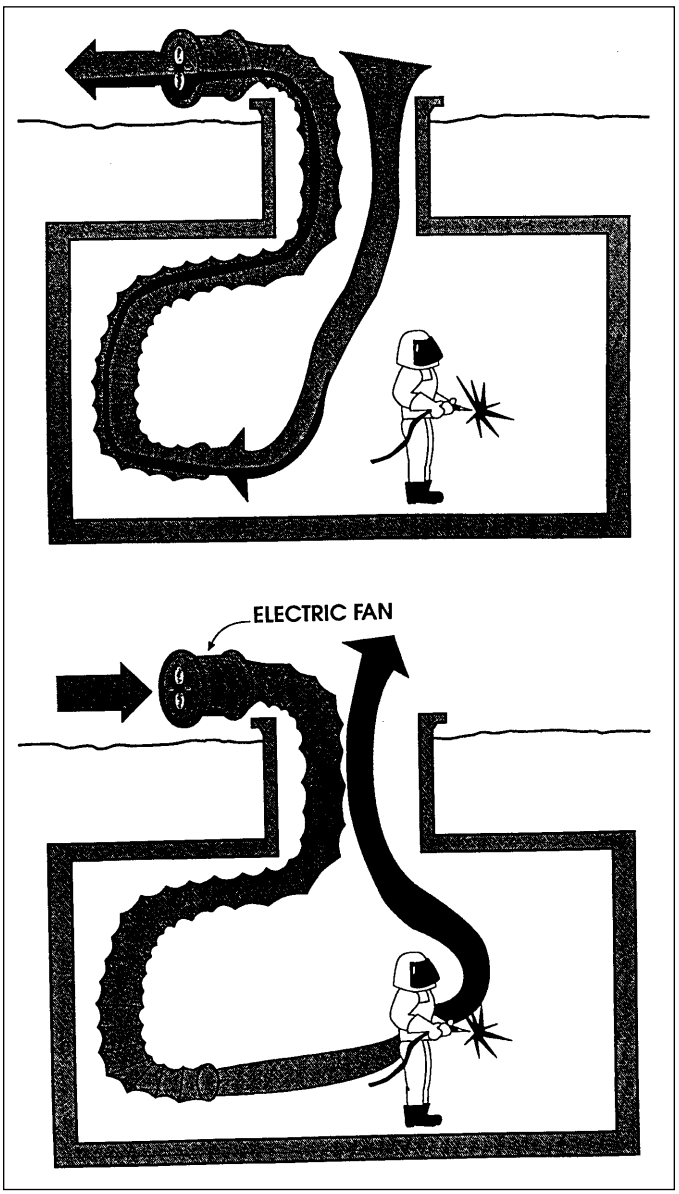


Figure 20–7. An exhaust fan cannot direct airflow (top). The same fan system blowing air (bottom) can direct airflow, and is much more effective in diluting contaminants in the work zone. (Courtesy ExxonMobil Corporation.)

The axial flow fans often used for dilution ventilation in enclosed spaces may exhibit a severe drop in airflow (Q) with added resistance to airflow. For each fan the amount of air it can move depends on the resistance or static pressure it is operating against. In enclosed spaces the extra resistance usually is due to either long lengths of duct attached to the fan, or too small openings for make-up air, which causes a slight negative air pressure inside the space. Fan manufacturers provide literature that shows how much air will be moved against varying static pressure levels. For fans used with flexible ducts the data sheets will show the airflow with different duct lengths.

Fans used for dilution in enclosed workspaces may be powered by electricity or compressed air. Air-powered units typically have air channels in the fan blades so that a jet of air is discharged at the blade tip to cause fan rotation. For air-driven fans, the fan's airflow at different compressed air pressures will be shown in the manufacturer's literature. Air-driven fan units should not be used to blow air into the workspace unless the compressed air is of respirable quality.

MEASURING DILUTION PERFORMANCE

A description of air measuring devices and techniques is in Chapter 19, Local Exhaust Ventilation.

Smoke tubes are useful in identifying the air distribution patterns in the work area, the movement of contaminants from discrete sources, the direction of natural air movement, and problems such as short-circuiting.

Volumetric airflow is determined from this equation:

$$Q = V \times A \qquad (7)$$

where Q = volumetric airflow, ft^3/min
V = velocity, ft/min
A = area of flow, ft^2

Velometers are used to determine the velocity through openings. For a space that is being exhausted, it may be easier and more accurate to measure the make-up air flowing into the space rather than measure the fan's output directly.

Where accurate airflow data is needed, follow the instructions for a *Velocity Traverse* in Chapter 19, Local Exhaust Ventilation.

SUMMARY

Dilution occurs when contaminants released into the workroom mix with air flowing through the room. It is used in situations where small quantities of relatively low toxicity (or low fire hazard) contaminants are released into the workroom air, and sufficient dilution occurs before workers breathe the contaminated air or a flammable mixture reaches a source of ignition. The major difficulty in designing a dilu-

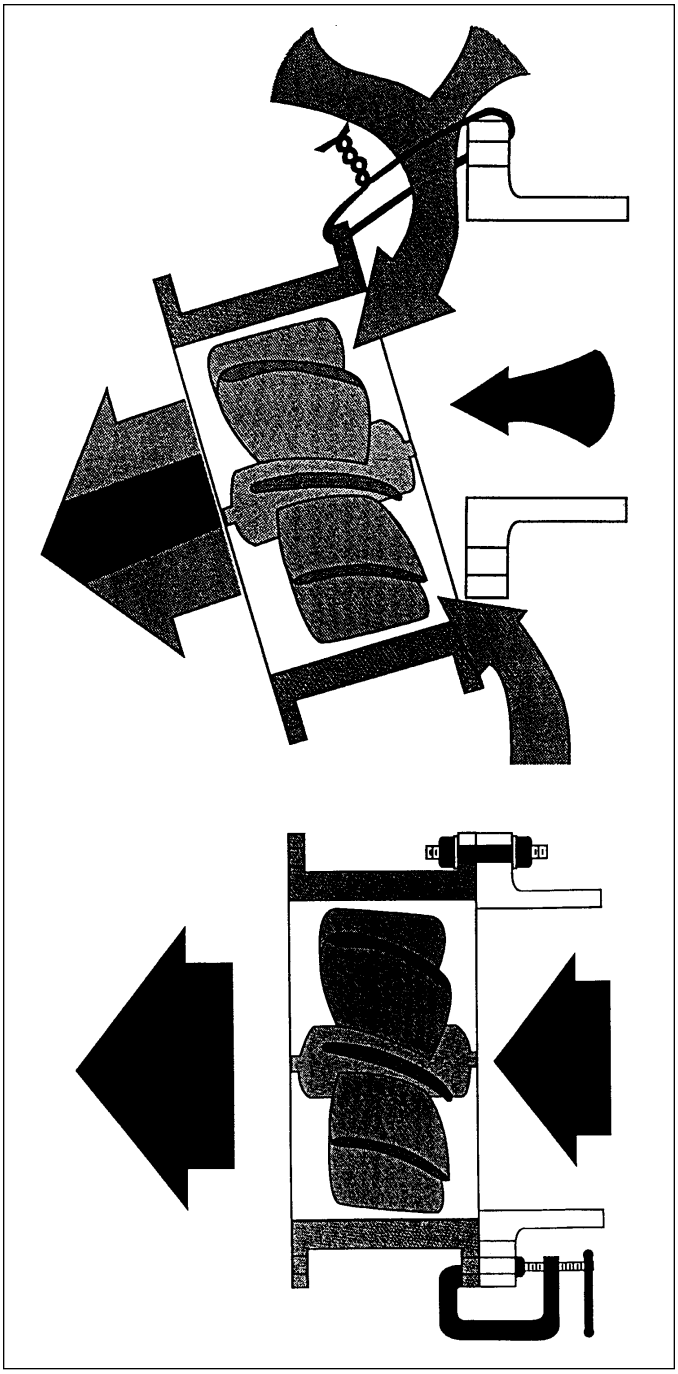


Figure 20–8. A gap in the fan mounting on a ventilation port (top) causes recirculation of outside air through the fan. A tight connection (bottom) maximizes the quantity of air exhausted from the workspace. (Courtesy ExxonMobil Corporation.)

tion ventilation system is that the inherent uncertainties that exist in many of the design parameters require that large "safety factors" be applied to airflow equations to assure that safe conditions are maintained. This can result in large air volumes being exhausted from the workplace.

Dilution is also used to ventilate workspaces such as tanks and utility vaults that are usually unoccupied but occasionally require workers to enter for inspection, cleaning, maintenance or other tasks. Work in confined or enclosed spaces presents special hazards, and work in these locations where hazards either exist or might develop requires extraordinary care. Effective use of dilution in these situations require careful application of the general principles that apply to all work settings plus additional concepts unique to confined or enclosed spaces.

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Chapter 21

General Ventilation of Nonindustrial Occupancies

by D. Jeff Burton, PE, CIH, CSP
revised by Peggy Kivel, CIH

Heating, ventilating, and air conditioning (HVAC) systems are built to provide adequate amounts of fresh, clean, and tempered air to employee occupants of a building. Fresh "outdoor" air (OA) is used to maintain concentrations of indoor airborne chemicals to below detectable or unhealthy levels.

The recommended quantity of fresh air (cubic feet of fresh outside air per minute per person, written commonly as cfm OA/person) has varied over the years. Figure 21–1 shows the history of ASHRAE OA recommendations.

ENERGY CONSERVATION VERSUS INDOOR AIR QUALITY (IAQ)

During the 1970s and 1980s, many buildings were built or remodeled to minimize air-handling energy costs. This often meant limiting the amount of outside air brought into the building, sometimes to as low as 0–5 cfm OA/person. During the same time, many new building methods and materials were introduced, some of which created new air contaminants. This has often resulted in underventilated buildings and occupants who complain about the air quality.

TERMS

Air-handling unit (AHU) is the ventilation equipment in HVAC systems.

ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) is the primary North American association dealing with IAQ issues; has developed a number of IAQ–related standards.

Acceptable indoor air quality is air in which there are no known contaminants at harmful levels as determined by appropriate authorities, *and* air with which 80 percent or more of the people do not express dissatisfaction based on

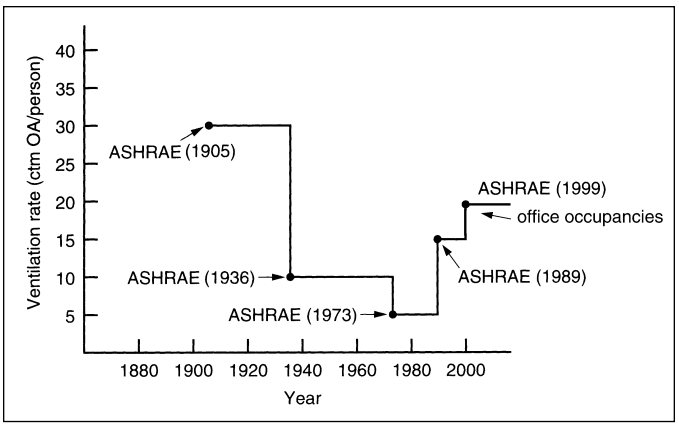

Figure 21–1. Outdoor air consensus standards over the years.

several acceptability criteria (such as temperature, relative humidity, odors, and air movement).

Commissioning is the acceptance process in which an HVAC system's performance is determined, identified, verified, and documented to ensure proper operation in accordance with codes, standards, and design intentions.

Constant air volume (CV) is an HVAC system in which the supply air volume is constant; temperature and humidity are varied at the air-handling unit (AHU).

HVAC (heating, ventilating, and air conditioning, pronounced "H-Vac") systems are air-handling systems designed primarily for temperature, humidity, odor, and air-quality control.

Occupied zone is usually the region within an occupied space between the floor and 72 in. above the floor and more than 2 ft from the walls.

Outdoor air (OA) is "fresh" air; the OA is mixed with return air (RA) to dilute contaminants in the supply air (SA); outdoor air is usually obtained from outside the building, but alternatives exist (such as from an acceptable hallway).

Supply air (SA) is air supplied to a space by the air-handling system.

Variable air volume (VAV) refers to HVAC systems in which the air volume is varied by dampers or fan speed controls to maintain the temperature; primarily used for energy conservation.

HVAC SYSTEMS

The term *HVAC* implies mechanically ventilating, heating, cooling, humidifying, dehumidifying, and cleaning air for comfort, safety, and health. HVAC systems also provide odor control and maintain oxygen and carbon dioxide levels at acceptable concentrations. Mechanical air-handling systems (as opposed to natural ventilation, which relies on wind and temperature differences to induce airflow through a building) range from a simple fan to complex, digitally controlled central air-handling units.

Individual units may be installed in the space they serve, or central units can be installed to serve multiple areas.

Zones

HVAC systems are built to serve specific *zones*, areas within a building that are served by an air handling system. The smaller the zone, the better chance there is of providing satisfactory conditions. But the costs increase as size decreases and the number of zones increases.

Most zones are defined by one thermostat. Some systems are designed to provide individual control of room air temperature in both single- and multiple-zone systems. (See Figure 21–2.)

The following paragraphs describe basic systems.

SINGLE-ZONE CONSTANT-VOLUME SYSTEM

The designer (or user) of an air-handling system must choose combinations of volume flow rate, temperature, humidity, and air quality that satisfy the needs of the space. Figure 21–3 shows a schematic of a simple, ideal commercial HVAC system. Systems vary in design and complexity, but the single-zone constant-volume (SZCV) system is the simplest.

Every central HVAC system has an OA *intake*, usually a louvered opening on the top or side of the building. As air enters the intake, pushed by atmospheric pressure, a *damper* regulates the amount of OA taken into the system. Intake dampers should have a minimum set point such that an adequate supply of outside air is delivered to building occupants at all times. (See Figure 21–3.)

Incoming outdoor air (OA) mixes with return air (RA) from the occupied space, forming recirculated air, or mixed air (MA). The MA usually passes through a coarse *filter* (arrestance filter), which removes bees, flies, bird feathers, leaves, and larger dust particles. Small particle collection requires a more efficient filter, the dust spot filter. The air then enters the *fan*.

Discharged at the fan outlet, the air, now under positive pressure, is pushed through coils that heat and cool the air depending on air temperature, the season, and the zone being served. A drain pan is fitted below the coils to collect water that condenses on the cooling coil. Leaving the coils,

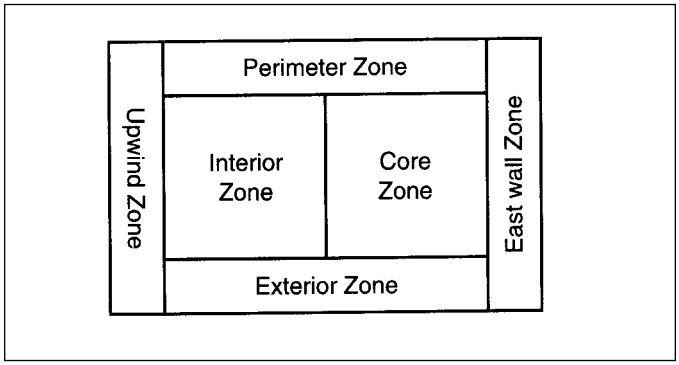

Figure 21–2. Zone terms.

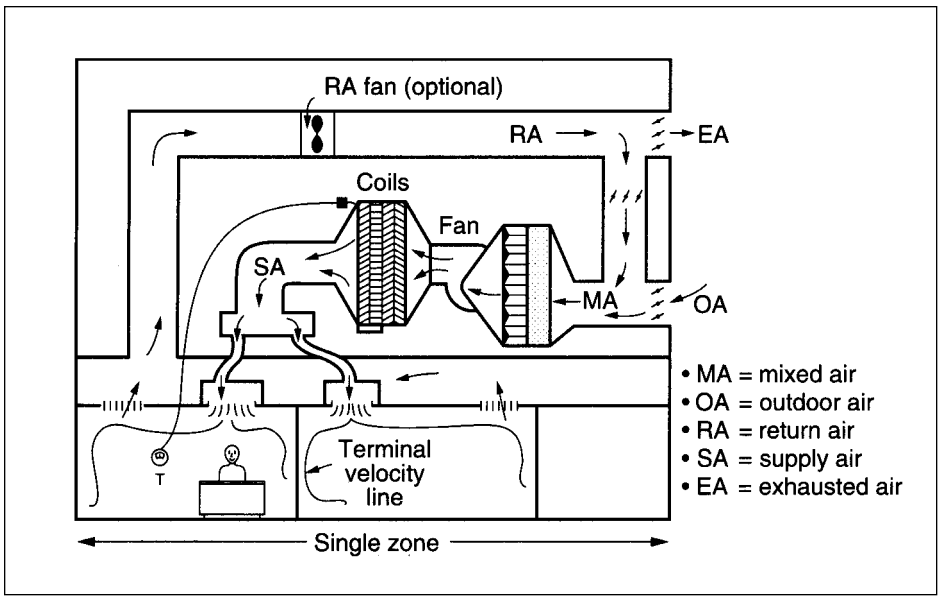

Figure 21–3. Typical single-zone constant-volume HVAC system. Note: MA = mixed air; OA = outside air; RA = return air; SA = supply air; EA = exhausted air. (Source: Burton, *IAQ and HVAC Workbook,* 1995.)

the air may be humidified (or dehumidified), which adjusts the relative humidity to 30–60 percent.

Typically, the conditioned air moves through metal ductwork (sometimes insulated with a sound-absorbing lining that must be kept dry and mold-free) at about 10–20 mph (1,000–2,000 fpm) to a distribution *box*. From there it travels through smaller ducts to the supply *terminals*, or *diffusers*.

Entering the room at 500–1,000 fpm, the air usually hugs the ceiling and walls, and its velocity slows to a terminal velocity of about 40–50 fpm. For comfort reasons, it is important that supply air reaches terminal velocity before it reaches building occupants—as higher velocities will cause drafts and thereby discomfort.

In about five to ten minutes, the air migrates through the space to the *return air register*, often a louvered opening into a return air duct or a return air plenum, the space above the ceiling tiles. From there it moves to the return air duct, where it may be recirculated (RA) or be exhausted to the outdoors (EA). Many buildings are maintained under positive pressure, and air may exfiltrate anywhere along the building periphery. Sophisticated controls manage the system and determine how much OA will be introduced, how much RA will be exhausted, and what temperatures and humidities will be maintained.

Figure 21–4 shows how a single constant-value (CV) supply system can provide temperature control in multiple zones. Each zone has a reheat coil controlled by a thermostat. Air is first cooled at the central cooling coil and then reheated at the final distribution point to maintain proper temperature. These systems are less energy efficient because they both cool and reheat the air.

Figure 21–5 shows another approach, which serves many zones from one air handler. The air is split before the heating and cooling coils. Dual ducts carry heated and cooled air to final mixing boxes near the zones. Thermostats control dampers that mix the appropriate amounts of air to achieve the desired temperature. Energy use is high, but individual control is also high.

VARIABLE AIR VOLUME SYSTEMS

In contrast to the constant-volume system, which varies air temperature to maintain temperature, a *variable air volume* (VAV) system varies the amount of air delivered to the space to maintain temperature. (See Figure 21–6.) For example, in summer, if the temperature increases, additional cool air is provided. As the space temperature drops to desired levels, the airflow diminishes. These systems are energy efficient, but they may cause problems of insufficient outside air. For example, if the space does not call for cool air, the airflow will drop, perhaps to zero flow in poorly performing HVAC systems.

In cases where a minimum volume of air is required, reheat coils must be installed to provide temperature control.

The advantages of variable airflow are energy conservation and lower operating costs. Air volume and fan speed (in rpm) are linearly related. If the airflow is to be cut in half, then fan speed is cut in half. But horsepower and speed are related through a third-power relationship. If the speed is reduced by

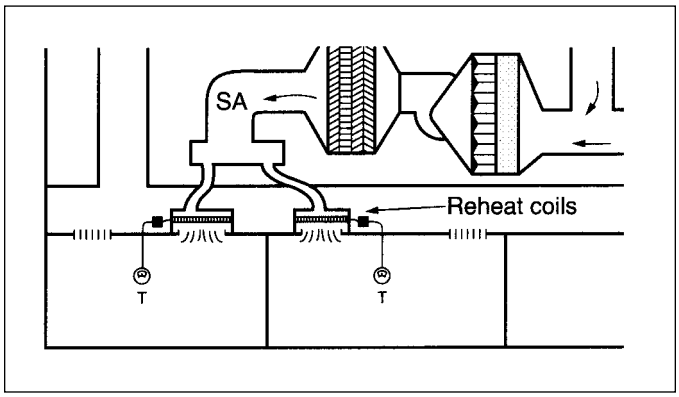

Figure 21–4. CV reheat system.

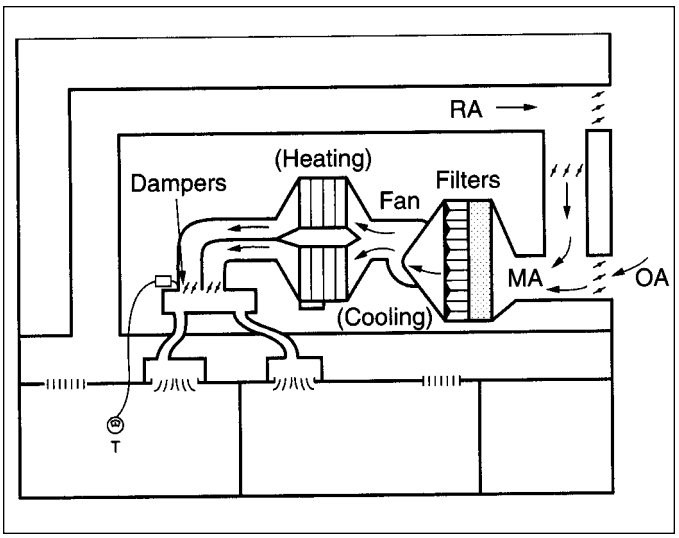

Figure 21–5. Dual-duct HVAC system.

half, the horsepower and the costs are reduced by eight times. The use of fan inlet dampers to reduce airflow also results in lower costs (but not by the same factors as reducing fan speed).

If variable-volume boxes are installed at the distribution point, more zones can be accommodated from a single fan. As the demand for air decreases, dampers at the boxes close, and the fan slows, saving energy. (See Figure 21–7.)

Reheat coils can be installed at each distribution box to regulate temperature where a minimum airflow is desired. This increases costs, however. Another way to maintain a minimum OA supply is to provide dual ducts with cool and warm air. Mixing boxes mix the air, always at the minimum flow required for temperature control and OA delivery, thus allowing the fan to run at the lowest rpm.

UNIT VENTILATORS

Unit systems can stand alone. (See Figure 21–8.) All of the air movement, OA delivery, and heating and cooling must be provided by the unit. These are often seen in offices with windows, hotel rooms, and other locations requiring self-contained operation.

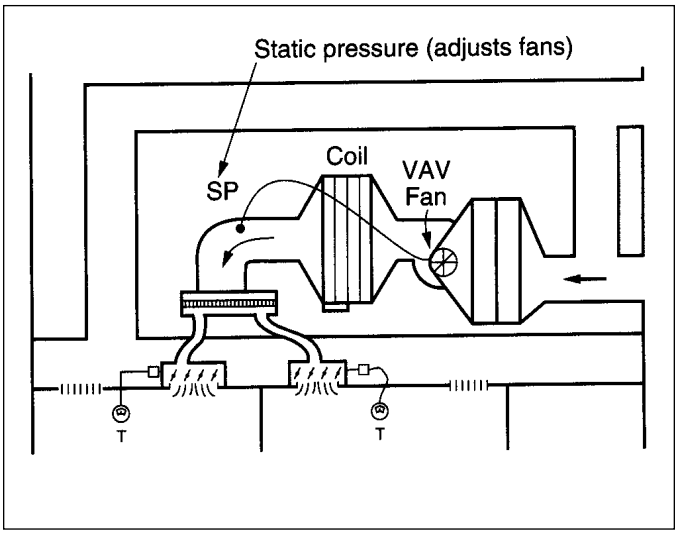

Figure 21–7. VAV with variable-air boxes.)

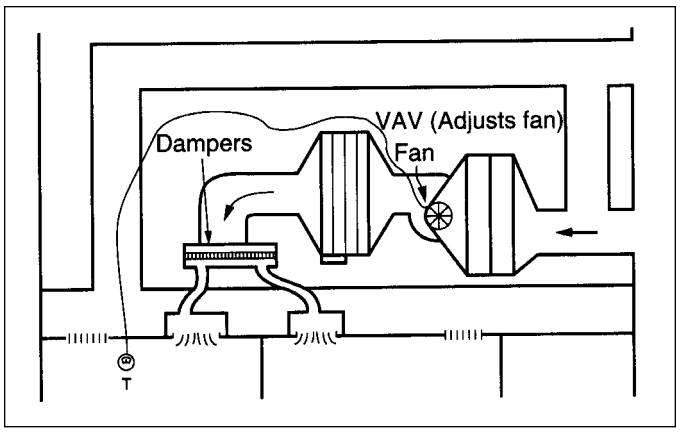

Figure 21–6. VAV HVAC system.

Complex systems may have combinations of multiple zones, variable air volumes, and dual ducts.

AIR MIXING IN THE OCCUPIED ZONE

Delivery of air to a space does not guarantee that proper mixing will occur. Offices with partitions are often susceptible to this problem. The placement of bookshelves, furniture, windows, and walls changes the movement of air, often for the worse. This problem is often quantified by calculating the *mixing efficiency* or *ventilation effectiveness*. The *mixing factor* is defined as the ratio of the amount of air required to dilute a contaminant to the ideal amount of air that should reduce it.

$$K_m = \frac{Q_{\text{actual}}}{Q_{\text{ideal}}} \tag{1}$$

Example

An office building houses 30 employees. ASHRAE Standard 62–1999 calls for 20 cfm OA per person to be delivered to the occupied zone.

$$Q_{\text{ideal}} = 20 \bullet 30 = 600 \text{ cfm} \tag{2}$$

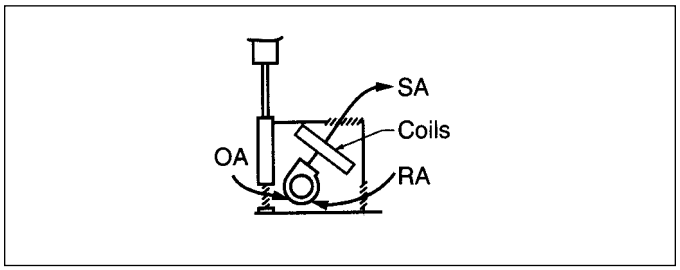

Figure 21–8. Unit ventilator.

If because of poor mixing it actually takes 800 cfm to provide 20 cfm OA per person, then

$$K_m = \frac{Q_{actual}}{Q_{ideal}} = \frac{800 \text{ cfm}}{600 \text{ cfm}} = 1.3 \quad (3)$$

In well-planned buildings served by good HVAC systems, K_m is often close to 1.0 (perfect mixing). Good mixing can be attained by the following approaches:

- ➢ Provide and properly position an adequate number of supply and return registers.
- ➢ Place supply registers so as to circulate air to where people are located in the occupied zone.
- ➢ Provide free-standing fans for people located in areas of poor mixing. (This approach is often cost-effective and satisfying to building occupants.)

DAMPERS

Dampers are used in HVAC duct systems to control airflow. Damper positions can be set automatically or manually depending on the type and sophistication of the HVAC control system. Fire and smoke dampers are used to restrict the spread of heat and smoke during a fire. Dampers, actuators, and control systems should always be checked and maintained regularly to ensure proper flow of air through the system.

TERMINAL DEVICES

Supply diffusers, return and exhaust grilles, and associated dampers and controls are used to produce proper distribution of the supply air. The number, location, and type of terminal devices determine the air distribution in the occupied space. Improper devices can lower the ventilation effectiveness and create stagnant areas, drafts, odor buildup, uneven temperatures, short-circuiting of the air, and air stratification.

RETURN AIR SYSTEMS

Where the space above the ceiling (the return plenum) is used for returning air, certain practices should be followed:

- ➢ Electrical wiring should be in conduit or coated with a special fire-resistant covering.
- ➢ Plastic piping and plastic air registers, such as polyvinyl chloride, should not be used because of the smoke they produce in a fire.
- ➢ The space should be kept clean and dry to reduce bioaerosol amplification.
- ➢ Fire walls (which extend to the floor above) must be breached, sometimes with backdraft dampers, to allow the air to return to the AHU.
- ➢ Ceiling tiles and access doors must be kept in place to ensure proper airflow in the occupied space.

From the return plenum, air enters the return ducts and is ducted to the central AHU. Some systems use return fans to ensure proper pressure relationships between the supply and return ducts.

HVAC SOURCES AND CAUSES OF IAQ PROBLEMS

NIOSH, in studies of over 1,300 IAQ episodes since the late 1970s, categorized major causes or sources of IAQ problems (rounded to the nearest 10 percent):

- ➢ Fifty percent related to deficiencies in the ventilation of the building, such as lack of outside air, poor air distribution, uncomfortable temperatures and humidities, and sources of contaminants in the system.
- ➢ Thirty percent related to some indoor air contaminant, such as formaldehyde, solvent vapors, dusts, or microbiological agents.
- ➢ Ten percent could be attributed to an outdoor source, such as motor vehicle exhaust, pollen, fungi, smoke, or construction dusts.
- ➢ Ten percent had no observable cause.

Note that about half of all IAQ episodes had their origin in the HVAC system. According to NIOSH, common patterns emerge from HVAC-origin IAQ problems:

- ➢ Forced ventilation is common.
- ➢ Buildings are energy-efficient.
- ➢ People perceive they have little control over their environment (for example, there is no thermostat in the room).
- ➢ There are more complaints when population densities are higher.

Table 21–A lists typical deficiencies and their causes.

HVAC STANDARDS FOR MAINTAINING ADEQUATE IAQ

Consensus Standards

The three most important consensus standards affecting IAQ are ASHRAE 62 on Ventilation for IAQ, ASHRAE 55 on Thermal Comfort, and ASHRAE 52 on Air Filtration. The latest standards are described in the following paragraphs.

ASHRAE 62–1999: VENTILATION FOR ACCEPTABLE AIR QUALITY

The following paragraphs provide a list of the most important provisions of the standard. The "shoulds" and "shalls" are taken directly from the standard.

- ➢ When mechanical ventilation is used, provision for airflow measurement should be provided. When natural ventilation is used, sufficient ventilation should be demonstrable. (Section 5.1)
- ➢ Ventilation air shall be supplied throughout the occupied zone. This implies delivery to where people actually are, as opposed to simply delivering air to the building. (Section 5.2)
- ➢ Where *variable air volume systems (VAV)* are used, and when the supply of air is reduced during times a space is occupied, indoor air quality shall be maintained throughout the occupied zone. (Section 5.3)
- ➢ Ventilation systems should be designed to prevent the growth and dissemination of microorganisms (e.g., limit

Table 21–A. ***Deficiencies in HVAC Systems and Their Causes***

Deficiency	*Potential Causes/Typical Problems*	*Potential Corrections*
Insufficient total air delivery to occupied space	Inadequate fan capacity	Increase fan speed
	Worn fan blades	Replace/repair wheel
	Faulty fan components	Provide maintenance
	Imbalanced air-supply system	Balance air-distribution system
	Increased number of occupants	Increase air capacity; redistribute occupants
Insufficient outdoor air (OA) delivered to occupied space	OA dampers set too low	Increase OA; provide fixed minimum OA delivery
	Imbalanced supply and return systems	Balance systems
	OA damper controls inoperative	Inspect, calibrate, reset controls
	Temperature-control capacity insufficient to meet space needs	Increase system capacity
Air distribution within space not adequate; improper; insufficient	Improper supply system balancing	Rebalance
	Poorly operating dampers, boxes	Repair, maintain, inspect boxes and control equipment
	Maladjustment of thermostat/controls	Calibrate thermostats
	Improper location of supply diffuser	Relocate diffusers or occupants
	Diffusers blocked	Remove obstructions
	Office partitions resting on floor	Raise or remove partitions
	Diffusers not attached to supply ducts	Inspect, reattach connecting ductwork
AHU components not operating properly	System does not start before arrival of occupants; shuts down before departure	Reformat controls
	Filters inadequate	Use appropriate filters; install filters in accordance with manufacturer's instructions; change filters on a regular basis
	Room temperature and humidity controls inoperative	Monitor or calibrate; maintain

Source: D. Jeff Burton, *IAQ and HVAC Workbook.*

use of fiber-lined ductwork where it may get dirty or wet). (Sections 5.4 and 5.5)

- ➢ Inlets and outlets shall be located to avoid contamination of intake air. (Section 5.4)
- ➢ Where practical, exhaust systems shall remove contaminants at the source. (Section 5.6)
- ➢ Where combustion sources, clothes dryers, or exhaust systems are used, adequate makeup air should be provided. (Section 5.7)
- ➢ Where necessary, particle filters and gas/vapor scrubbers should be sized and used to maintain air quality. (Sections 5.8 and 5.9)
- ➢ Relative humidities should be maintained between 30 and 60 percent. (Section 5.10)
- ➢ AHU condensate pans shall be designed for self-drainage. Periodic in-situ cleaning of cooling coils and condensate pans shall be provided. (Section 5.11)
- ➢ AHU shall be easily accessible for inspection and preventive maintenance. (Section 5.11)
- ➢ Steam is preferred for humidification. Standing water used in humidifiers and water sprays should be treated to avoid microbial buildup. (Section 5.11)
- ➢ Special care should be taken to avoid entrainment of moisture drift from cooling towers into makeup air and intake vents. (Section 5.11)
- ➢ Indoor air should not contain contaminants at concentrations known to impair health or cause discomfort. Outdoor air introduced to the building through the ventilation system should not exceed USEPA National Primary Ambient-Air Quality Standards. If the outdoor air contaminant levels exceed EPA values, the air should be treated. When confronted with air known to contain contaminants not on the EPA list, one should refer to other references for guidance. (Section 6)
- ➢ The standard lists minimum OA requirements for about 100 occupancies, including offices and classrooms. (See the sample shown in Table 21–B.) The standard assumes good mixing and distribution of the outdoor air. It also assumes a certain occupant loading. Where these are not the case, additional OA may be required (Section 6.1.3).

ASHRAE 55–1992: THERMAL ENVIRONMENTAL CONDITIONS FOR HUMAN OCCUPANCY

The standard specifies conditions in which 80–90 percent or more of the occupants should find the environment thermally acceptable. It does not address other environmental factors such as air quality and contaminants. This standard attempts to predict what conditions of temperature, humidity, activity, clothing, air movement, and radiant heat sources will satisfy 80–90 percent of the people.

Table 21–B. *Sample of OA Required by ASHRAE 62-1999 for Specific Occupancies*

Application	Estimated Maximum Occupancy per 1,000 ft²	cfm/person OA
Commercial dry cleaner	30	30
Office space	7	20
Smoking lounge	70	60
Conference room	50	20
Laboratories	30	20

Satisfaction for any single parameter (such as temperature) should be 90 percent or more, and the satisfaction expressed for all parameters collectively should be 80 percent or more.

Figure 21–9 summarizes the standard's provisions for temperature and humidity. The figure is a simplified version of the original, which uses "operative temperatures" and concepts that can be understood only by reading the actual standard. (See the Bibliography.)

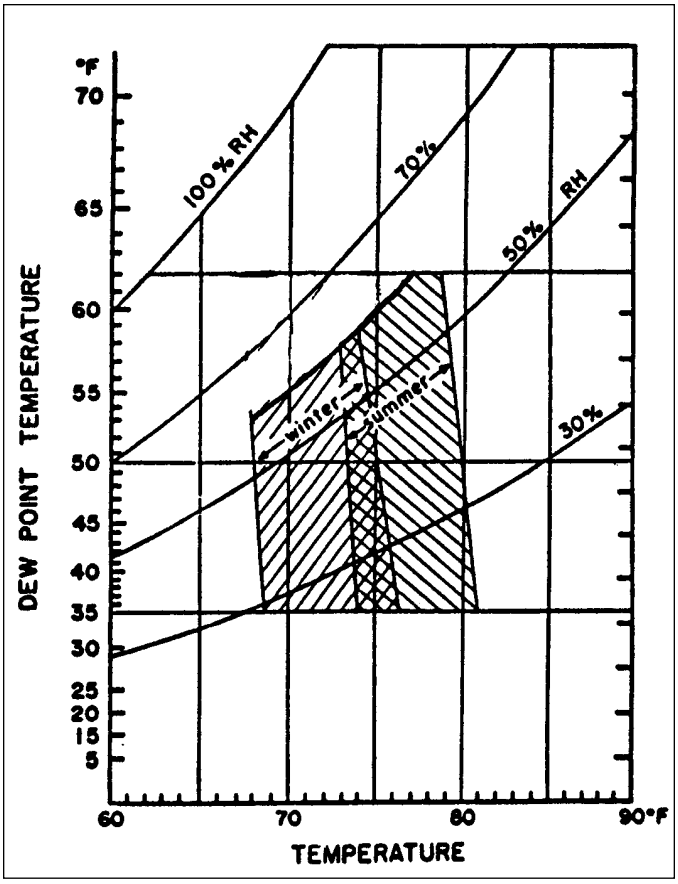

Figure 21–9. Thermal comfort standard. (Adapted from ASHRAE 55-1992.)

ASHRAE 52: 1992 Methods of Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter

Most modern HVAC systems use two filters: a roughing filter to remove large particles and a dust spot filter to remove smaller particles. (Charcoal filters and HEPA filtration systems may be used in rare instances to remove gases, vapors, and very small particles.) The three performance characteristics of greatest importance in selecting an air filter are as follows:

- ➢ The filter's efficiency in removing particles from the airstream
- ➢ The resistance to airflow through the filter
- ➢ The time interval between cleaning or replacement

ASHRAE 52 has established two testing or rating procedures:

- ➢ The ASHRAE Dust Spot Efficiency test, sometimes referred to as the 52 Atmospheric test, uses a fine dust as the test medium.
- ➢ The ASHRAE Arrestance test uses a coarse dust as the test medium.

Each has its place, but the dust spot efficiency test is used with filters that capture smaller particles. For example, a fine open foam filter with an arrestance rating of 80 percent may have a dust spot efficiency rating of 20–25 percent, and 0 percent for the very small DOP test aerosols used for testing HEPA filters.

Typical comparisons are shown in Table 21–C, by percent removal.

Regulatory Standards

All existing buildings were built to comply with local building and fire codes in force at the time of construction (or rebuilding). Many building code authorities have adopted some version of ASHRAE 62 and 55. You should check your local codes.

As of May 2000, OSHA was in the process of developing an IAQ regulation for places of employment. The proposed OSHA rule on IAQ included the following major provisions related to ventilation:

- ➢ Keep carbon dioxide levels below 800 ppm; this translates into an OA requirement (in typical office spaces) of 25–30 cfm.
- ➢ Keep relative humidity below 60 percent (which is consistent with ASHRAE 55–1992).
- ➢ Obtain and maintain records on HVAC systems.
- ➢ Inspect, maintain, and operate the HVAC system so that it meets the criteria of the codes in force at the time the building was constructed.
- ➢ Exhaust designated smoking areas to the outdoors and keep the area under negative pressure.
- ➢ Locate intakes to prohibit uptake of contaminated air.
- ➢ Provide local exhaust of specific emitters if necessary.

OSHA also estimated that it would cost about $1.40 per square foot (for problem buildings) to upgrade existing HVAC systems to meet the proposed standard, for a total of $12 billion for the country. Call your local state or federal

Table 21–C. ***Comparison of Filter Tests***

	Percent Removal for Specific Filter Media (%)		
Filter Media	*Arrestance Test*	*Dust Spot Test*	*DOP Test***
Fine open foams	70–80	15–30	0
Cellulose mats	80–90	20–35	0
Wool felt	85–90	25–40	5–10
Mats, 5–10 μm, 1/4 in.	90–95	40–60	15–20
Mats, 3–5 μm, 1/2 in.	>95	60–80	30–40
Mats, 1–4 μm, fibers	>95	80–90	50–75
Mats, 0.5–2 μm, glass	—	90–98	75–90
Wet-laid glass fibers, HEPA*	—	—	95–99+

* HEPA: High-efficiency particulate air filters.
** A test used primarily with HEPA filters.

OSHA area office for the latest information on the status of this important regulation.

TESTING, TROUBLESHOOTING, AND MAINTAINING HVAC SYSTEMS

In order for any HVAC system to operate properly and consistently over its life span, *commissioning*, *testing*, *troubleshooting*, and *maintenance* are required.

Commissioning is a process in which a new HVAC system's performance is identified, verified, and documented to ensure proper operation and compliance with codes, standards, and design intentions. Commissioning often requires tests and demonstrations to verify that the system operates properly. Troubleshooting and maintenance activities also require system testing. A *commissioning agent* is often chosen by the building owner, the architect, or the contractor to oversee construction and commissioning activities.

Testing and balancing (TAB or T&B) is periodically required for all systems. This involves the testing and adjusting of system components (such as dampers) to ensure adequate air distribution to the occupied spaces. When hiring a TAB specialist, put requirements on paper in the form of a performance specification. Always check for references and certifications, such as those issued by the National Environmental Balancing Bureau (NEBB). You can obtain detailed information from your local Sheet Metal and Air Conditioning National Association (SMACNA).

Most health and safety professionals are not able to conduct in-depth testing of HVAC systems. Specialized knowledge of testing and balancing is required on the complex HVAC systems of today. This chapter provides guidelines for *simple* testing and troubleshooting that non-HVAC personnel might perform. For example, most people should be able to do the following:

- ➢ Become familiar with the HVAC system characteristics
- ➢ Determine the intended or desired operating parameters
- ➢ Perform cursory ventilation checks with smoke tubes, balometers, velometers, and pressure-measuring equipment

Early on, the investigator should contact the building engineer or a person who intimately knows the HVAC system. (Sometimes this person is the only one who really knows how the system operates "now that the system has been modified so much," a common problem.) Try to have that person available during the investigation.

Simple initial checks of the ventilation in a room that anyone can perform are shown in Table 21–D.

Simple measurements of the ventilation in a room that anyone can perform are shown in Table 21–E.

One approach to becoming familiar with an HVAC system is to follow the system from start to finish. Go first to the air intakes and follow the air as it flows through the dampers, filters, fans, coils, ductwork, terminal boxes, and supply registers. Then identify return grills and follow the air back to the air handler. The following should be noted:

- ➢ Air intake and exhaust locations and damper settings
- ➢ What equipment is actually running and what is shut down
- ➢ Closed or jammed dampers
- ➢ Clogged or misplaced filters
- ➢ Settled water anywhere
- ➢ Thermostat locations and temperature levels
- ➢ Supply air quality (clean, odorless, properly humidified)
- ➢ Drafts or stuffiness in occupied space
- ➢ Supply and return register locations and damper settings
- ➢ Potential sources of contaminants (microbial or chemical) anywhere
- ➢ Provision for OA
- ➢ Positioning of OA and RA dampers
- ➢ Controls operation
- ➢ VAV system air delivery schedule, minimums

Next, review the as-built and as-modified drawings to become familiar with the HVAC system and the building. Read the original (or modified) specifications to become familiar with the intended operating parameters.

Forms 21–1 and 21–2 and Checklists 21–1, 21–2, and 21–3 (at the end of the chapter) can help you organize your information-gathering and testing efforts.

Table 21–D. *Simple Checks of the HVAC System in a Room*

➢ Does the room have a supply diffuser? A return?
➢ Is air moving through diffusers and return grills?
➢ Are air diffusers and grills open? Blocked? Attached to ductwork?
➢ Is supply air distributed throughout the occupied space?
➢ Do people actually feel air moving?
➢ Are there dead air spaces in the office or room?
➢ Do printers, copiers, and other equipment have adequate ventilation?
➢ Are mixing fans or portable heaters used by occupants?
➢ Does the HVAC system always operate when people are in the building?
➢ Is the air too hot? Too cold? Too humid? Too dry?
➢ Do people actually detect odors?
➢ Do occupants report symptoms that they associate with air quality?
➢ What contaminates the air?

Simple Calculations for Characterizing the Airflow in a Space

A number of simple calculations are available to the health and safety professional for determining air volume flow rates, the amount of OA being delivered to a space, and so forth. All of the equations presented in Chapter 20 can also be used in IAQ applications. Additionally, the following approximations are helpful.

PERCENTAGE OF OUTDOOR AIR IN THE SUPPLY AIR

It is possible to estimate the percentage of outdoor air (OA) in the supply air (SA) by measuring the temperatures of the air.

$$\%\,\text{OA} = \frac{T_{RA} - T_{MA}}{T_{RA} - T_{OA}} \bullet 100 \qquad (4)$$

Table 21–E. *Simple Measurements of Indoor Air-Quality Parameters*

What to Measure	*Typical Equipment*
In occupied space Dry-bulb temperature Wet-bulb temperature Relative humidity	Thermometer, psychrometer
System temperatures Supply air (SA) Outdoor air (OA) Mixed air (MA) Return air (RA)	Thermometer
CO_2 measurements Supply air (SA) Outdoor air (OA) Return air (RA) Occupied space air	Detector tubes, CO_2 monitors
Air movement Any location	Smoke tubes, velometers

where T_{RA} = temperature of return air (dry-bulb)
T_{MA} = temperature of mixed return and outside air (dry-bulb)
T_{OA} = temperature of outdoor air (dry-bulb)

For example, assume the following temperatures were measured in an air-handling unit: T_{RA} = 70 F, T_{MA} = 66 F, and T_{OA} = 50 F. The percentage of OA can be estimated by the following equation:

$$\%\,\text{OA} = \frac{T_{RA} - T_{MA}}{T_{RA} - T_{OA}} \bullet 100 = \frac{70 - 66}{70 - 50} \bullet 100 = 20\% \qquad (5)$$

ESTIMATING THE AMOUNT OF OA IN AN OFFICE SPACE

Outdoor air (OA) reduces the indoor contaminants to concentrations that are acceptable to a majority (if not all) of the occupants in a space. Carbon dioxide is used as a surrogate for other air contaminants. It has been suggested that building owners and operators maintain CO_2 concentrations below 1,000 ppm. In their 62–1999 standard, ASHRAE recommended maintaining a steady-state concentration of CO_2 no greater than 700 ppm above outdoor levels as an indicator of body odor acceptability. The concentrations of carbon dioxide in a building vary with the number of sources (people) and the volume of OA introduced and mixed in the space. (See Figure 21–10.) Note that concentrations tend to build and decay exponentially over time. This behavior allows us to predict airflow rates from measurements of carbon dioxide.

TRACER GAS APPROACHES TO DETERMINING THE OUTDOOR AIRFLOW RATE IN A SPACE

The airflow through a building, space, or room can be estimated using tracer gas methods. Three methods are widely used: the *concentration-decay* method, the *constant-emission* method, and the *constant-concentration* method. All three methods are based on a simple relationship:

$$\text{Change in tracer-gas concentration} = \text{Amount introduced} - \text{Amount removed} \qquad (6)$$

The change in tracer gas is related to the nature of the airflow and the source of the tracer gas. Carbon dioxide, as well as other inert gases and vapors, can be used as tracer gas in

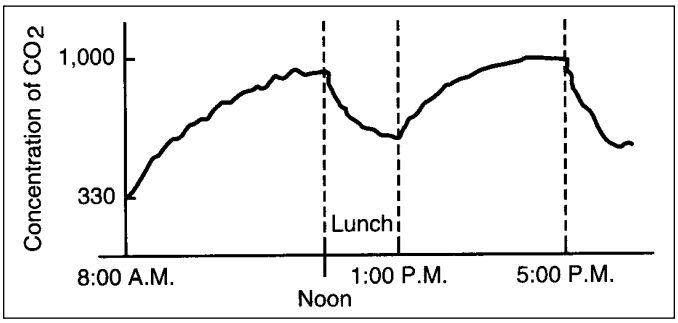

Figure 21–10. Typical carbon dioxide concentrations in today's buildings.

occupied spaces. The sources listed in the Bibliography at the end of this chapter contain more information on tracer-gas calculations. The following simple estimating techniques are based on techniques using carbon dioxide as the tracer gas.

A useful approximation of the volume flow rate of outdoor air is based on the *constant-emission* technique. The number of people working in an office space and the measured carbon dioxide concentrations in the space (after the concentration has leveled off) are generally related to the volume flow rate of outdoor air as follows:

$$Q_{OA} \approx \frac{13{,}000\,n}{C_{indoors} - C_{OA}} \tag{7}$$

where Q_{OA} = approximate volume flow rate of outdoor air (cfm)
n = number of people working in an office complex (with about seven people per 1,000 ft_2 of office space)
$C_{indoors}$ = measured concentration of CO_2 in the office air after a long period of occupancy time, such as near lunch or near the end of the day (ppm)
C_{OA} =concentration of CO_2 in the outdoor air (ppm)

Example
Suppose 12 employees work in an office complex. After several hours the measured CO_2 concentration has leveled off at about 1,000 ppm. The outside concentration of CO_2 is 340 ppm. The approximate volume of outdoor air being introduced to the space is calculated as follows:

$$Q_{OA} \approx \frac{13{,}000 \bullet n}{C_{indoors} - C_{OA}} \approx \frac{13{,}000 \bullet 12}{1{,}000 - 340} \approx 240 \text{ cfm} \quad (20 \text{ cfm/person}) \tag{8}$$

Perhaps the easiest and most useful method of measuring air-exchange rates over short periods of time is the *concentration-decay* tracer-gas approach. Human-origin carbon dioxide concentrations are used as the tracer gas. During the day CO_2 builds up naturally; after everyone leaves at 5:00 p.m., OA will dilute the carbon dioxide. (See Figure 21–10.) Knowing the initial and final concentrations and the time elapsed allows the use of purge formulas to predict the amount of OA delivered.

$$N = \frac{\ln(C_i - C_o) - \ln(C_a - C_o)}{h} \tag{9}$$

where N = air exchange, air changes per hour, OA
C_i = concentration of CO_2 at start of test
C_o = outdoor concentration, about 330 ppm
C_a = concentration of CO_2 at end of test
h = time elapsed between start and end of test
ln is the natural log.

When using this equation, be sure the HVAC system operates normally during the time of the test. (Many HVAC systems automatically reduce service at or before quitting time.) Be sure that almost all of the people have left the building or space being measured. Measure background carbon dioxide outside the building, if possible. A good location is at the air intake for the HVAC system. Be sure to subtract background concentrations from your measured values. If the decay line is flat, then no OA is being supplied. If the decay line is uneven (not smoothly exponential), then the air in the space is not being uniformly mixed in the space.

Volume flow rates can be calculated from the following formula:

$$Q_{OA} = \frac{N \bullet \text{Vol}}{60} \tag{10}$$

Example
Suppose the carbon dioxide concentration is C_i = 1,200 ppm at 5:30 p.m., when all of the people have departed a building. By 7:30 p.m., the concentration has been reduced to C_a = 400 ppm. The outside concentration is 330 ppm. How many air changes per hour of OA does this suggest? What is Q_{OA} for a space volume of 50,000 ft^3?

$$N = \frac{\ln(C_i - C_o) - \ln(C_a - C_o)}{h} \tag{11}$$

$$N = \frac{\ln(1{,}200 - 330) - \ln(400 - 330)}{2} = 1.26 \text{ AC/h OA} \tag{12}$$

$$Q_{OA} = \frac{N \bullet \text{Vol}}{60} = \frac{1.26 \times 50{,}000}{60} = 1{,}050 \text{ cfm} \tag{13}$$

It is possible to estimate the percentage of outdoor air in the supply air by measuring the carbon dioxide concentrations at the AHU and using the following equation:

$$\%\ \text{OA} = \frac{C_{RA} - C_{SA}}{C_{RA} - C_{OA}} \bullet 100 \tag{14}$$

where C_{RA} = CO_2 concentration in return air
C_{SA} = CO_2 concentration in supply air (any point after the return air and outdoor air have mixed)
C_{OA} = CO_2 concentration in outdoor air

Example
Assume the following concentrations of CO_2 are measured at the air-handling unit:

$$C_{RA} = 750 \text{ ppm}$$
$$C_{SA} = 650 \text{ ppm} \tag{15}$$
$$C_{OA} = 330 \text{ ppm}$$

The percentage of OA is calculated as follows:

$$\% \text{ OA} = \frac{C_{RA} - C_{SA}}{C_{RA} - C_{OA}} \cdot 100 = \frac{750 - 650}{750 - 330} \cdot 100 = 24\% \quad (16)$$

Additional information on estimating airflow rates can be found in the references listed in the Bibliography.

Troubleshooting HVAC Systems

Invariably, something goes wrong with almost all ventilation systems. Simple troubleshooting usually involves three phases of study:

- ➢ Characterizing complaints and gathering background data
- ➢ Checking performance of ventilation systems and their controls
- ➢ Measuring carbon dioxide, temperature, and relative humidity

First, the troubleshooter should talk to those who are complaining to characterize the problem, gather background data, and try to establish causes or sources of the problem.

The most common causes and sources of trouble related to ventilation systems are as follows:

- ➢ Insufficient outdoor air (OA) introduced to the system
- ➢ Poor distribution/stratification of supply air in occupied space
- ➢ Draftiness—too much supply air or improper terminal settings
- ➢ Stuffiness—not enough air delivery or not delivered properly
- ➢ Improper pressure differences—doors hard to open
- ➢ Temperature extremes—too hot or too cold
- ➢ Humidity extremes—too dry or too humid
- ➢ Poor filtration—dirt, bugs, or pollen in the air-delivery system
- ➢ Poor maintenance
- ➢ Energy conservation the number-one priority
- ➢ Settled water in system
- ➢ Visual evidence of slime or mold
- ➢ Improper balance of distribution system
- ➢ Dampers at incorrect positions
- ➢ Terminal diffusers not at correct positions
- ➢ VAV systems in nondelivery or low-delivery mode

If after investigating the troubleshooter has identified one or more problems, he or she should not overreact; it is probably not a life-threatening situation. Furthermore, correction of the problems may or may not satisfy those who are registering complaints. Corrective measures do not hurt, of course, and any measures taken to solve the problem will probably be appreciated.

The following paragraphs list some common maladies or complaints and potential causes or sources of trouble.

The temperature is too warm (or too cold). Potential problems: thermostats misadjusted, supply air temperature setting too high or low, too much or too little supply air, supply diffuser blows air directly on occupants, temperature sensor malfunctioning or misplaced, cold air not mixing with occupied space air, HVAC system defective or undersized, and building under negative pressure, which causes infiltration of air at the building perimeter (building pressures should be +0.03 to +0.05 in. wg). Simple testing equipment: thermometer, velometer, smoke tubes.

The air is too dry (or too humid). Potential problems: Humidity controls not operating correctly or undersized. Simple testing equipment: sling psychrometer.

The air is stuffy, stagnant or *There is no air movement.* Potential problems: Nondelivery or low delivery of air to space, filters overloaded, VAV dampers malfunctioning, restrictions in ductwork, ductwork disconnected from supply diffusers, duct leaking, inadequate delivery of outside air, and blockage from furniture, partitions, or other barriers in the occupied space. Simple testing equipment: thermometer, velometer, smoke tube, CO_2 meter.

There is no air movement when it gets cold. Potential problems: VAV system set to deliver no air when system is not calling for cooling (common problem in older VAV systems). Simple testing equipment: thermometer, velometer, smoke tube, CO_2 meter.

There are too many drafts. Potential problems: Occupant outside of occupied zone, supply diffuser set to blow air directly on occupant, occupant near open door or window, free-standing fan blowing on occupant. Simple testing equipment: velometer, smoke tube.

Air has a musty, "dirty sock" smell. Potential problem: Microbiological contamination. Simple testing equipment: noses, visual inspection. Sampling may be warranted.

Air smells like diesel exhaust. Potential problems: Air intake near loading dock, other diesel engine exhaust source. Simple testing equipment: velometer, smoke tube, indicator tubes.

Checklists 21–4 and 21–5 (at the end of the chapter) are useful in checking and troubleshooting existing systems.

Operation and Maintenance

Correct operating procedures and maintenance of the HVAC system will ensure its continued and consistent effectiveness. Maintenance is time-consuming and expensive but has been proven to be cost-effective. Labor-intensive maintenance (a general rule is one maintenance person per floor of building) requires trained workers, good materials, and good management. Preventive maintenance (PM) programs usually prevent problems before they arise.

Checklists 21–6, 21–7, and 21–8 (at the end of the chapter) can be helpful in establishing a good PM management program.

Lapses in maintenance activity require repair and renovation (for example, when ducts must be cleaned because filters have been left to deteriorate).

Dirt, debris, and microbiological growths in ductwork can be minimized by the following measures:

- ➢ Well-maintained filter systems (at least 40–60 percent efficiency, dust spot test)
- ➢ Regular HVAC maintenance
- ➢ Good housekeeping in the occupied space
- ➢ Locating air intakes in noncontaminated locations
- ➢ Keeping all HVAC system components dry (or drained)

Ducts can become both the source and the pathway for dirt, dust, and biological contaminants to spread through the building. ASHRAE 62–1999 and other standards suggest that efforts be made to keep dirt, moisture, and high humidity from ductwork. Filters must be used and kept in good working order to keep contaminants from collecting in the HVAC system.

Duct contaminants may include hair and dander, skin particles, insects and insect parts, organic and inorganic dust, carbon and oil particles, glass fibers, asbestos, pollen, mold, mildew, bacteria, leaves, dirt, and paper—all of which *may* contribute to IAQ problems. On the other hand, the mere presence of these contaminants has no effect on people if the contaminants do not leave the duct, if they do not generate other contaminants (for example, organic dust may support growth of mold or release adsorbed volatile organic compounds), or if they do not generate odors. Indeed, there have been cases where inert and inactive dusts were stirred up during duct cleaning, resulting in occupant complaints. Most ducts have small amounts of dust on their surfaces—a common occurrence that almost never necessitates duct cleaning.

Duct cleaning or replacement is generally warranted in the following conditions:

- ➢ There is slime growth in the duct.
- ➢ There is permanent water damage.
- ➢ There is debris that restricts airflow.
- ➢ Dust is actually seen issuing from supply registers.
- ➢ Offensive odors come from the ductwork.

Duct cleaning should be performed after one can answer "yes" to all of these questions:

- ➢ Are there contaminants in the ductwork?
- ➢ Has testing confirmed their type and quantity?
- ➢ Do they (or their odors or byproducts) leave the duct and enter the occupied space?
- ➢ Is the source of these contaminants known? Can the source be controlled? (If not, cleaning is only a temporary measure.)
- ➢ Do the contaminants actually cause IAQ problems?
- ➢ Will duct cleaning effectively remove (neutralize, inactivate) the contaminant?
- ➢ Is duct cleaning the only (or the most cost-effective) solution?
- ➢ Has a qualified and reputable duct-cleaning firm been identified?
- ➢ Have the firm's references been checked?
- ➢ Does the duct-cleaning firm have a sensible, sound approach? Does it have the right kind of equipment? Will the cleaning process protect your HVAC equipment and the occupants of the space during cleaning?
- ➢ Will the firm give a guarantee?

SUMMARY

The occupational health and safety professional has many tools with which to work when investigating, correcting, and controlling IAQ problems. The references that follow this chapter contain more detailed discussions of the particulars.

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Agencies and Associations Involved in IAQ

ACGIH (publications, reports, committee activity), (513) 742-2020; 1330 Kemper Meadow Dr., Cincinnati, OH 45240. (ACGIH.org)

AIHA (list of industrial hygiene consultants, IAQ committee reports), 2700 Prosperity Ave, Suite 250, Fairfax, VA 22031- 4319; phone (703) 849-8888. (aiha.org)

ASHRAE (numerous books, articles, standards; journal), (800-527-4723; 1791 Tullie Circle NE, Atlanta, GA 30329. (ashrae.org)

ASTM, 100 Barr Harbor Drive, West Conshohocker, PA 19428-2959, (610) 832-9585. (astm.org)

Associated Air Balance Council (AABC; sets standards for TAB of HVAC systems), 1518 K St. NW, Suite 503, Washington, DC 20005; phone (202) 737-2926.

Columbus IAQ Resource Committee (study of energy impacts of new ASHRAE 62-1989), City of Columbus, Ohio, 90 W. Broad St., Columbus, OH 43215.

National Air Duct Cleaners Association (NADCA; publications on duct cleaning, recommended standards for duct cleaning), 1518 K St. NW, Suite 503, Washington, DC 20005; phone (202) 737-2926. (NADCA.com)

NEBB, National Environmental Balancing Bureau (list of certified HVAC balancing firms, publications, standards, and practice for TAB), 8575 Grovemont Circle, Gaithersburg, MD 20877, phone (301) 977-3698. (NEBB.org).

NIOSH (lists of publications, studies of IAQ, standards, research), 4646 Columbia Parkway, Cincinnati, OH 45226; phone (513) 841-4382. (www.cdc.gov/NIOSH/homepage.html)

SMACNA (publication *Indoor Air Quality*, sheet metal, ductwork), 4201 Lafayette Center Dr., Chantilly, VA 20151; phone (703) 803-2980. (smacna.org).

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U.S. EPA (general publications on the subject, conducts research, training, information dissemination), 1200 Pennsylvania Avenue, NW, Washington, DC 20460. (epa.gov/iaq)

FORM 21-1

Quick HVAC Survey Worksheet

Name _____ Date_____

Contact_____ Location _____

Phone _____ _____

Potential Problem	Yes/No	Comments
Lack of outside air	_____	_____
Inadequate air distribution	_____	_____
Pressure difference between rooms	_____	_____
Air infiltration at perimeters	_____	_____
Detectable odors	_____	_____
Excessive tobacco smoke	_____	_____
Temperature too warm	_____	_____
Temperature too cold	_____	_____
Humidity too high	_____	_____
Humidity too low	_____	_____
Poorly vented heating equipment	_____	_____
Poorly located intakes	_____	_____
Visible mold, slime	_____	_____
Water visible	_____	_____
Water-damaged furnishings	_____	_____
Cleaning chemicals stored in mechanical room	_____	_____
Deteriorated insulation	_____	_____
Dirty, organic debris	_____	_____
Poor HVAC maintenance	_____	_____
Improper exhaust ventilation	_____	_____
Poorly located loading docks	_____	_____
Other	_____	_____
Other	_____	_____

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

FORM 21-2

Space Characterization Worksheet

Location _____ Date/time _____

Name _____ Address/phone _____

Contact _____ Number working in space _____

Sketch

Show doors, windows,
supply and return registers,
dimensions; show floor plan
or other necessary detail.
Use reverse side for more.

L _____ W _____ H _____ Room Volume _____

T_{DB} _____ T_{WB} _____ R.H. _____

C_{CO_2} _____ C_{other} _____ C_{other} _____

T_{MA} _____ T_{RA} _____ T_{OA} _____ % OA _____

C_{SA} _____ (CO_2) C_{RA} _____ (CO_2) C_{OA} _____ (CO_2) % OA _____

Supply volume flow rates (SA)*: Q_1 _____ Q_2 _____ Q_3 _____

Q_4 _____ Q_5 _____ Q_6 _____ $Q_{SA\ total}$ _____

Return volume flow rates (RA)*: Q_1 _____ Q_2 _____ Q_3 _____

Q_4 _____ Q_5 _____ Q_6 _____ $Q_{RA\ total}$ _____

Q_{OA} _____ $Q_{OA/person}$ _____ AC/h _____

Terminal (draft) velocities _____ Location _____

Pressure relationship with hallways: (+) or (–) Light _____ Noise _____

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-1

Building Information Checklist

Building:_____ Contact Person: _____

Address: _____ Telephone: _____

Date:_____ Investigator: _____

Building Description

Year built_____ HVAC type_____ Interior layout_____
Occupants_____ Owner_____ Date occupied_____
Construction_____ Number of floors_____ Neighborhood type_____
Emission sources_____ Traffic pattern_____ Location of garages_____
Interior construction _____ Tightness of doors, windows_____ Insulation type_____

Occupant Space Description

Number of people_____ ft^2 / person_____ Type of activity_____
Smoking policy_____ Number of smokers_____ Chemicals present_____
Cleaning materials_____ Furnishings_____ Construction materials_____
Recent construction_____ Recent changes_____ Free-standing fans_____
Temperature, humidity_____ Mold/dirt_____ Wet surfaces_____
Adjacent space_____ Room pressure_____ Carbon dioxide_____
Drafts_____ Stuffiness_____ Interviews_____

HVAC Systems

Type of system_____ Condition_____ Windows_____
Type of fuel_____ Type of diffuser_____ Location of intakes_____
Location of exhaust_____ OA provisions_____ Distribution_____
Terminal velocities_____ Noise_____ Dust/dirt_____
Economizer cycle_____ Controls_____ Zones_____
Total cfm_____ Total OA_____ Heat exchanger_____
Local exhaust_____ Makeup air_____ Duct type_____
Water in system_____ Type humidifier_____ Restroom exhaust_____
Air-cleaner type_____ Air-cleaner efficiency_____ Person in charge_____

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-2

Building Owner's HVAC Documentation and Programs

( ) References and calculations for required supply rate of OA
( ) Methods of measuring/monitoring OA supply
( ) Description of OA control systems
( ) Description of OA control systems for VAV systems
( ) Documentation of temperature/humidity control systems
( ) Filtration descriptions and SOP for use
( ) Filter efficiency documentation
( ) Written preventive maintenance program
( ) Maintenance record keeping
( ) Written Standard Operating Procedures
( ) Plans, drawings, specifications of building (as built/as is)
( ) Plans, drawings, specifications of building mechanical systems (as built/as is)
( ) Schematic drawings showing locations of all HVAC equipment for nonengineers
( ) Manufacturer literature for all operating equipment
( ) Testing, balancing, and monitoring records
( ) Building permits, stack permits, other applicable licenses/permits
( ) History of changes to HVAC systems, occupancies
( ) Technical information about control systems
( ) Other_____
( ) Other_____

Note: In order to ensure IAQ, building operators should maintain these minimum programs, records, and documents.

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-3

Basic Information Checklist for HVAC Systems

Plans, drawings, specifications, changes _____
The type of system (VAV, constant volume) _____
Which rooms have windows that open? _____
Location of air intakes _____
Location of AHUs _____
Percent OA _____
How is OA percentage determined? _____
How are each of the following controlled (automatic, manual, who, when, how)? _____
Fans
- OA damper_____
- Supply terminal dampers_____
- Temperature_____
- RA, SA, fan dampers_____
- Humidity_____
- Air distribution_____

Type of filtration
- Arrestance/dust spot efficiency _____
- Filter maintenance _____

What is the maintenance program for each of the following (frequency, how, who, when)?
- Fan components _____
- Drive components _____
- Filters _____
- Drain pans, traps, valves, nozzles _____
- Dampers _____
- Controls _____

For return air systems (RA)
- Location _____
- Plenum or duct _____
- Lining _____

For ducts
- Type _____
- Insulation (inside, outside, material) _____
- Inspection, cleaning, repair _____

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-4

Inspection Checklist for HVAC Systems

Outdoor Air Intakes
- Location _____
- Open _____
- Controllable _____
- Outdoor contaminant sources nearby _____
- Type _____
- Location of exhausts _____
- Predominant wind direction and velocity _____

HVAC Equipment
- Intact _____
- Dry _____
- Clean _____
- Equipment running in accordance with specifications _____
- Filters in place, operating _____
- Slime, mold, dirt, soot removed _____

Ductwork
- Intact, connected _____
- Dry _____
- Balanced _____

Supply Air Diffusers

Open _____ Set _____
Airflow correct _____ Terminal velocities _____
Air jet profile _____ Location _____
Clean _____ Quiet _____

Return Air Grills
- Location _____
- Air movement _____
- Open _____
- Attached to return system _____

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-5

HVAC Troubleshooting Checklist
Typical Problems

( ) Insufficient outdoor air (OA) introduced to the system
( ) Intake and exhaust dampers inoperative, malfunctioning
( ) Intake and exhaust at improper location

( ) Poor roughing filtration—dirt, bugs, pollen in air-delivery system
( ) Inadequate dust spot filtration
( ) Poor system maintenance

( ) Improper balance of distribution system
( ) Distribution dampers at incorrect positions
( ) Building under negative pressure

( ) Terminal diffusers not at correct positions
( ) VAV systems in nondelivery or low-delivery mode
( ) Terminal diffusers not attached to delivery system

( ) Poor distribution or stratification of supply air in occupant space
( ) Draftiness—too much supply air or improper terminal settings
( ) Placement of desks, personnel locations in high-velocity areas

( ) Stuffiness—not enough air delivery or not delivered properly
( ) Improper pressure differences between rooms—doors hard to open
( ) Temperature extremes—too hot or too cold

( ) Humidity extremes—too dry or too humid
( ) Energy conservation has become number 1 priority
( ) Settled water in system

( ) Visual evidence of slime or mold

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-6

Checklist for Preventing and Minimizing IAQ Problems Through Good HVAC Practices

( ) Maintain the HVAC system in top working condition.
( ) Provide a written operating and maintenance plan for HVAC systems.
( ) Specify building materials with low volatile organic compounds (VOCs) emissions.

( ) Provide appropriate volumes of outside air.
( ) Provide good distribution and mixing of supply air.
( ) Specify furnishings and materials with low VOC emissions.

( ) Restrict smoking to areas with dedicated ventilation systems.
( ) Use lowest temperatures consistent with energy and comfort.
( ) Provide relative humidities of 30–50 percent.

( ) Use high-efficiency filters (ASHRAE dust spot efficiency 50–70 percent).
( ) Involve and educate occupants.
( ) Lower occupant densities.

( ) Increase occupant control of environment (with, for example, personal fans, more thermostats, involvement in decisions).
( ) Involve professional assistance in IAQ problems.
( ) Provide monitoring of systems, air quality.

( ) Eliminate standing or stagnant water.
( ) Remove contaminated or emitting materials that cannot be controlled.
( ) Investigate bakeout for new buildings.

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

CHECKLIST 21-7

Maintenance Checklist for Common HVAC Components

Unit Ventilators
( ) Brush and vacuum grills, coil, fan and unit interior.
( ) Remove any debris.
( ) Check belts and belt tightness.
( ) Repair any leaking water source.
( ) Inspect, clean, and/or replace filters.
( ) Adjust and lubricate dampers.
( ) Operation okay (controls, air delivery).

Induction Units
( ) Same as above, plus investigate air intake area for potential contaminants.

Reheat Coils, Mixing Boxes (Dual-Duct and VAV Systems)
( ) Clean coils.
( ) Inspect box and duct to ensure tight connection.
( ) Inspect, adjust, and lubricate dampers.
( ) Check operation and controls.
( ) Check minimum delivery, OA.

Humidifiers
( ) Determine type (water, water spray, wet steam, or dry steam).
( ) Check and clean water strainers, traps, and valves.
( ) Check and clean float equipment.
( ) Clean drains and drain pans.
( ) Inspect for slime, mold, odor.
( ) Clean spray nozzles.
( ) Check controls, instruments.

Cooling Towers
( ) Check for mold, slime.
( ) Wash down interior, plates.
( ) Clean head pans and nozzles.
( ) Drain and flush pipelines, pumps, tower pans.
( ) Clean strainers and screens.
( ) Operating in accordance with manufacturer's specs.

Source: D. Jeff Burton, *IAQ and HVAC Workbook.*

CHECKLIST 21-8

Checklist for Reducing Microbial Problems in HVAC Systems

( ) Prevent buildup of moisture in occupied spaces.

( ) Prevent moisture collection in HVAC components.

( ) Remove stagnant water and slime from mechanical equipment.

( ) Use steam for humidifying.

( ) Avoid use of water sprays in HVAC systems.

( ) Maintain relative humidity less than 70 percent.

( ) Use filters with a 50–70 percent collection efficiency rating.

( ) Find and discard microbial-damaged furnishings and equipment.

( ) Remove or manage room humidifiers.

( ) Provide preventive maintenance of HVAC systems.

( ) Provide pigeon screens on intakes and exhausts (this will prohibit the contamination of the system by bird droppings, feathers, nesting materials, food, and so forth).

Source: D. Jeff Burton, *IAQ and HVAC Workbook*.

Chapter

22

Respiratory Protection

by Craig E. Colton, CIH

A primary objective of industrial hygiene programs in industry is the control of airborne contaminants by accepted engineering and work practice control measures. When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators must be used. The Occupational Safety and Health Administration (OSHA) has established a standard, 29 CFR *1910.134 Respiratory Protection, for regulating the use of respiratory-protective equipment.*

If the environment is still not completely safe after effective engineering and work practice controls have been fully used in reducing exposure to the lowest possible level, it will be necessary to use respirators to protect workers from contact with airborne contaminants or oxygen-deficient environments. Respiratory-protective equipment varies in design, specifications, application, and protective capability. Proper selection depends on the contaminant involved, conditions of exposure, human capabilities, and respirator fit.

Respirators are the least satisfactory means of exposure control because they provide good protection only if they are properly selected, fit tested, worn by the employees, and replaced when their service life is over. In addition, some employees may not be able to wear a respirator due to health or physical limitations. Respirators can also be cumbersome to use and hot to wear, and they may reduce vision and interfere with communication.

Despite these difficulties, respirators are the only form of protection available in the following situations: during the installation or implementation of feasible engineering and work practice controls; in work operations such as maintenance and repair activities for which engineering and work practice controls are not yet sufficient to reduce exposure to or below the permissible exposure limit (PEL); and in emergencies.

RESPIRATORY PROTECTION PROGRAMS

A written respiratory protection program must be established when respiratory protection is needed. It should include worksite-specific procedures covering the following minimum program elements:

- ➢ Procedures for selection of proper respiratory-protective equipment including exposure assessment
- ➢ Procedures for medical evaluation of respirator wearers
- ➢ Procedures for fit testing of workers using tight-fitting respirators
- ➢ Procedures for proper respirator use during routine and reasonably foreseeable emergency situations
- ➢ Procedures and schedules for cleaning, disinfecting, storing, inspecting, repairing, and discarding respirators
- ➢ Procedures to ensure adequate air quality, quantity, and flow of breathing air for atmosphere-supplying respirators
- ➢ Procedures for training workers on respirator use and respiratory hazards
- ➢ Procedures for regular program evaluation

In addition, a program administrator must be appointed to manage the program.

The OSHA standard requires that these points be addressed. The *American National Standard for Respiratory Protection*, Z88.2-1992, is a voluntary consensus standard for the proper use of respiratory-protective equipment. This standard is published by the American National Standards Institute (ANSI). It specifies similar points for a program, but it enumerates them slightly differently. It is highly recommended that the American National Standard be consulted as well as the OSHA regulation.

Worksite-Specific Procedures

Written worksite-specific procedures that cover the entire respiratory protection program need to be developed and implemented as they apply to each employer's own facility. The procedures need to cover all the elements of the program listed above as well as the issuance and purchasing of respirators and any company policies pertaining to respirator use. Each element must be covered in enough detail so it is clear exactly how each element will be accomplished. Restating the OSHA requirements such as, "We will do fit testing annually," does not suffice. The worksite-specific procedures must spell out exactly how the company intends to implement each program element at each worksite. Who will do the fit testing? Where will the fit testing be done? What protocol will be used? Examples of employer policies that may be included are disciplinary action for not using the respirator and facial hair. The program should be a tool to enhance worker protection.

In addition, written worksite-specific procedures must be developed for emergency and rescue operations. Although every situation cannot be anticipated, many of the needs for emergency and rescue use of respirators can be envisioned. This can be done by consideration of the following:

- ➢ An analysis of the emergency and rescue uses of respirators based on materials, equipment, work area, processes and personnel involved
- ➢ A determination, based on the above analysis, of whether the available respirators can provide adequate protection to allow workers to enter the potentially hazardous environments
- ➢ Selection of the appropriate type and numbers of respirators
- ➢ Maintenance of these respirators so that they are readily accessible and operational when needed.

Copies of these procedures must be available for the employees to read. The procedures need to be reviewed and revised as conditions and equipment change.

Exposure Assessment of Respirator Wearers

Exposure assessments are basic to the proper use of respiratory-protective equipment. This information is used not only to identify the need for respirators but also to identify the level of protection required. The information is also needed to establish the required change schedule for chemical cartridge and gas mask respirators used for gases and vapors. The levels of worker exposure are determined by instruments and equipment designed to measure the concentrations of air contaminants and oxygen. Adequate air sampling and analysis should be carried out to determine time-weighted average concentrations and, when appropriate, compliance with ceiling and short-term exposure limits as well. Other chapters in this book should be consulted for more detail.

Selection of Proper Respiratory-Protective Equipment

Selection of the proper respirator is a very important task. The respirator must be National Institute for Occupational Safety and Health (NIOSH) approved. Respirator selection must be based on an exposure assessment and relevant workplace and user factors. Although it is obvious that the respirator selection must be based on the hazard to which the worker is exposed, there are many points that must be considered. These issues will be discussed later in this chapter.

Medical Evaluations of Respirator Wearers

Respirators can impose several physiological stresses ranging from very mild restriction of breathing to burdens of great weight and effort. The type of effects produced depend on the type of respirator in use, the job, and workplace conditions. For this reason, a physician or other licensed health care professional (PLHCP) must determine whether or not an employee has any medical conditions that would preclude the use of respirators.

To assist the physician or other licensed health care professional, the program administrator must advise the physician or other licensed health care professional of the types and weights of respirators to be used for either emergency or routine use: typical work activities; expected physical work effort; additional protective clothing and equipment to be worn; environmental conditions, such as high heat; frequency and duration of respirator use; and hazards for which the respiratory-protective equipment will be worn.

Although it is generally agreed that relatively few nondisabling medical conditions make respirator use dangerous, especially for employees who need respirators only briefly or occasionally to perform their tasks, it is important to identify those employees who may experience difficulties. A medical evaluation to determine the worker's ability to use the respirator must be completed before the worker is fit tested or required to use the respirator. This *medical evaluation* may be performed by either administering a questionnaire or an *initial medical examination*. A copy of the questionnaire is in the OSHA respiratory protection standard (see the chapter addendum). Depending on the results of the initial medical evaluation, a *follow-up medical examination* may be required to investigate potential problems with respirator use. The follow-up medical examination must include any medical tests, consultations, or diagnostic procedures deemed necessary to make a final determination regarding ability to wear a respirator. Pulmonary function tests (spirometry) are not specifically required. They may be required during the follow-up medical examination, however, if the physician deemed the tests necessary to make a determination.

Additional medical evaluations are not required annually, however, they must be provided under the following conditions:

- ➢ An employee reports medical signs or symptoms that are related to ability to use a respirator
- ➢ A physician or other licensed health care professional, supervisor, or the respirator program administrator informs the employer that an employee needs to be reevaluated
- ➢ Information from the respiratory protection program, including observations made during fit testing and program evaluation, indicates a need for employee reevaluation
- ➢ A change occurs in workplace conditions (for example, physical work effort, protective clothing, and temperature) that may result in a substantial increase in the physiological burden placed on an employee.

A physician may require that additional medical evaluations be based on a specific frequency (for example, annually) or on a frequency based on the age of the worker. For example, a younger worker may receive an additional medical evaluation every three years whereas an older worker may receive one annually, even if not reporting difficulty with respirator use, problems during fit testing, or changes in the workplace.

For further information, consult the *American National Standard for Respiratory Protection-Respirator Use—Physical Qualifications for Personnel* and *Respiratory Protection Guidelines* from the American Thoracic Society (See Bibliography).

Respirator Fit

Each respirator wearer of a tight-fitting respirator (Figure 22–1) must be provided with a respirator that fits. To find the respirator that fits, the worker must be fit tested. This will be discussed later in this chapter. In addition, each respirator wearer must be required to check the seal of the res-

Figure 22–1a.

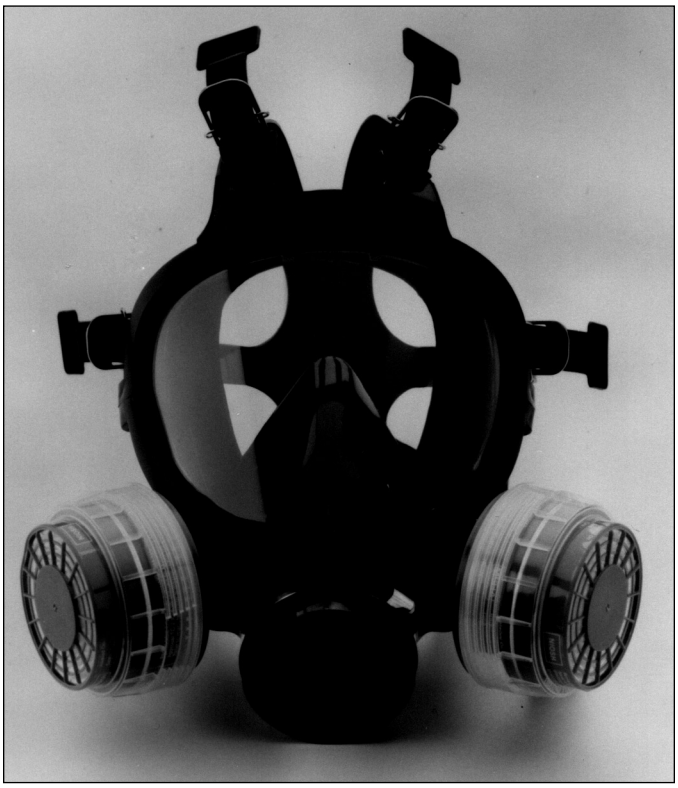

Figure 22–1b. The two types of tight-fitting respiratory inlet coverings: a. Half facepiece with P100 particulate filters. b. Full facepiece with cartridges and P100 particulate filters. (Courtesy 3M.)

Figure 22–2a.

Figure 22–2b.

pirator by appropriate means before entering a harmful atmosphere. Each respirator manufacturer provides instructions on how to perform these user seal checks. A user seal check is a test conducted by the wearer to determine if the respirator is properly adjusted to the face. The procedures may vary slightly from one respirator to another due to differences in construction and design. In general the employee is checking either for pressure or flow of air around the sealing surface. User seal checks are not substitutes for qualitative or quantitative fit tests. Care must be taken in conducting user seal checks. Thorough training in carrying out these tests must be given to respirator wearers.

A respirator equipped with a tight-fitting facepiece (Figure 22–1) must not be worn if facial hair comes between the sealing periphery of the facepiece and the face or if facial hair interferes with valve function. Only respirators equipped with loose-fitting hoods or helmets are acceptable with interfering facial hair (Figure 22–2b, c). If spectacles, goggles, or face shields must be worn with a half- or full-facepiece respirator, they must be worn so as not to adversely affect the seal of the facepiece to the face. Certain facepieces also enable the wearer to wear prescription spectacles without disturbing the facepiece seal.

Figure 22–2c. The three types of loose-fitting respiratory inlet coverings: a. Loose-fitting facepiece. b. Helmet. c. Hood. Respirators with loose-fitting respiratory inlet coverings do not need to be fit tested. The loose-fitting facepiece is not suitable for workers with beards because it forms a partial seal with the face. The loose-fitting helmet (b) and hood (c) are acceptable for workers with beards. (Courtesy 3M.)

Training

For the safe use of any respirator it is essential that the user be properly instructed in its use. Qualified persons must instruct supervisors as well as the person issuing respirators. Emergency and rescue teams must be given adequate training to ensure proper respirator use. The OSHA standard requires that all employees be trained in the proper use of the device assigned to them. Many companies have their employees sign a document attesting to their having completed a training session with the respiratory-protective equipment. As a minimum, written records of the names of those trained and the dates when the training occurred must be kept. The workers need to be trained upon initial assignment of a respirator and followed up with annual training.

Each respirator wearer must be able to demonstrate knowledge of at least the following:

- ➢ Why the respirator is necessary and how improper fit, usage, or maintenance can compromise the protective effect of the respirator
- ➢ What the limitations and capabilities of the respirator are
- ➢ How to use the respirator effectively in emergency situations, including situations in which the respirator malfunctions
- ➢ How to inspect, put on and remove, use, and check the seals of the respirator
- ➢ What the procedures are for maintenance and storage of the respirator
- ➢ How to recognize medical signs and symptoms that may limit or prevent the effective use of respirators
- ➢ The general requirements of the OSHA respiratory protection standard

The training must be conducted in a manner that is understandable to the employee and provided prior to requiring the employee to use a respirator in the workplace. In addition to being retrained annually, retraining must be performed when: changes in the workplace or respirator type make the previous training obsolete, inadequacies in the employee's knowledge or use of the respirator indicate that the employee has not retained the required level of understanding or skill, or any other situation arises in which retraining appears necessary to ensure safe respirator use. The training in putting on the respirator must include an opportunity to handle the respirator with instructions for each wearer in the proper fitting of the respirator, including demonstrations and practice in how the respirator must be worn, how to adjust it, and how to determine if it fits properly. Respirator manufacturers can provide training materials that tell and show how the respirator is to be adjusted, put on, and worn. The training session must also allow for time to practice. Hence, simply showing a videotape is not sufficient unless it is followed up with actual hands-on time. Close, frequent supervision can be useful to ensure that the workers continue to use the respirator in the manner they were trained. Supervisory personnel should periodically monitor the use of respirators to insure they are worn properly.

Respirator Maintenance

The respirator maintenance program includes cleaning and disinfecting of respirators where necessary, inspection of the equipment for defects, maintenance and repair of defects found, and proper storage of the respirator. A maintenance schedule should be implemented that ensures each worker is provided with a respirator that is clean, sanitary, and in good operating condition. The manufacturer's instructions should be followed. The precise nature of the program will vary because of such factors as size of the facility and the equipment involved.

CLEANING AND DISINFECTING

Personally assigned respirators must be cleaned and disinfected regularly. Respirators that may be worn by different individuals must be cleaned and disinfected before being worn by a different individual. Cleaner-disinfectants that effectively clean the respirator and contain a bactericidal agent are commercially available. The bactericidal agent is often a quaternary ammonium compound. For personally assigned respirators, equipment wipes containing these compounds are available. Wipes should not be the only method in place. Alternatively, respirators can be washed in a mild detergent solution (such as a dishwashing liquid) and then immersed in a disinfecting solution. Commonly recommended disinfecting solutions are an aqueous hypochlorite (bleach) solution and aqueous iodine solution; 50 ppm of chlorine and iodine, respectively. The recommended immersion time is two minutes. Strong cleaning and disinfecting agents and many solvents can damage rubber and elastomeric respirator parts. These substances should be used with caution. It is advisable to check the respirator manufacturer's instructions or contact them if there are questions.

INSPECTION

The respirator must be inspected by the wearer immediately prior to each use to ensure that it is in proper working order. In addition, emergency and rescue use respirators must be inspected at least monthly. Emergency escape-only respirators must be inspected before being carried into the workplace for use. All respirators that do not pass the inspection must be immediately removed from service and repaired or replaced. The respirators should also be inspected during cleaning to determine if they are in good condition or if parts need to be replaced or repaired or whether they should be discarded.

Respirator inspection must include a check for tightness of connections, for the condition of the respiratory inlet covering, head harness, valves, connecting tubes, harness assemblies, hoses, filters, cartridges, canisters, end-of-service-life indicator, electrical components, and shelf-life date(s). The inspection should also include a check for proper function of the regulators, alarms, and other warning systems. Compressed gas cylinders on self-contained breathing apparatus (SCBA) must be checked to ensure that they are fully charged. The cylinders must be recharged when the pressure

falls to 90 percent of the manufacturer's recommended pressure level.

The inspection of emergency use respirators must be certified by documenting the date the inspection was performed, the name (or signature) of the person who made the inspection, the findings, required remedial action, and a serial number or other means of identifying the inspected respirator. The information should be provided on a tag or label that is attached to the respirator storage compartment, is kept with the respirator, or is included in inspection reports stored as paper or electronic files. It must be kept until it is replaced by a subsequent certification.

REPAIR

Replacement of other than disposable parts and any repair should be done only by personnel with adequate training in the proper maintenance and assembly of the respirators. Replacement parts must be only those designated for the specific respirator being repaired. Failure to do so may result in malfunction of the respirator. In addition it will void the NIOSH approval.

STORAGE

The respirators must be properly stored in order to protect them from dust, sunlight, excessive heat, extreme cold, excessive moisture, damaging chemicals, and physical damage from things such as vibration and shock. Tool boxes, paint-spray booths, and lockers are not appropriate storage locations unless they are protected from contamination, distortion, and damage. In addition, emergency and rescue use respirators that are located in the work area must be readily accessible. Their location must be clearly marked.

Air Quality

When a program includes atmosphere-supplying respirators, then assurance of breathing air quality must be included. Compressed air, compressed oxygen, liquid air, and liquid oxygen used in atmosphere-supplying respirators must be of high purity. Oxygen must meet the requirements of the *United States Pharmacopoeia* for medical or breathing oxygen. Compressed gaseous air must meet the requirements for grade D as described in CGA G-7.1-1997. The limiting characteristics are listed in Table 22–A. When cylinders of purchased breathing air are used the employer must have a certificate of analysis from the supplier stating that the breathing air meets the requirements of Grade D. The moisture content of the cylinder air must not exceed a dew point of –50 F (–45.6 C) at one atmosphere pressure.

When compressors are used to supply breathing air, the moisture content must be controlled so that the dew point at one atmosphere pressure is 10 F (5.56 C) below the ambient temperature. Sorbent beds and filters that are used to ensure the air quality must be maintained and replaced or refurbished periodically following the manufacturer's instructions. A tag maintained at the compressor must contain the most recent change date and signature of the person authorized to perform the change.

Program Administration

Responsibility and authority for administration of a respiratory protection program must be assigned to one person who may and probably will have assistance from others. Centralizing authority and responsibility ensures that there is coordination and direction for the program. Respiratory protection programs will vary widely from company to company, and depends upon many factors; a program may involve specialists such as safety personnel, industrial hygienists, health physicists, and physicians. In small plants or companies having no formal industrial hygiene, health physics, or safety engineering department, the respiratory protection program should be administered by a qualified person responsible to the facility manager. The administrator must have sufficient knowledge to supervise the program properly. It is important that the administrator keep abreast of current issues, advances in technology, and regulations. In any case, overall responsibility must reside in a single individual if the program is to achieve optimum results.

The program administrator's responsibilities include the following:

- ➢ Conducting exposure assessments of the work area prior to respirator selection and periodically during respirator use to ensure that the proper respirator is being used
- ➢ Selecting the appropriate respirator that will provide adequate protection from all contaminants present or anticipated
- ➢ Maintaining records as well as the written procedures in a manner that documents the respirator program and allows for the evaluation of the program's effectiveness
- ➢ Evaluating the program's effectiveness through ongoing surveillance of the program

In addition to watching the program day to day, program evaluations must be performed periodically (such as yearly) in order to ensure that the program reflects the worksite-specific procedures and complies with current regulations and standards. The program must be periodically reevaluated to determine whether its goals are being met and changes are

Table 22–A. ***Grade D Breathing Air Requirements***

Limiting Characteristic	*Allowable Maxima*
Percent O_2 (balance predominantly N_2)	19.5–23.5 %
Water	Variable from very dry to saturated; no liquid water
Oil (condensed)	5 mg/m^3
Carbon monoxide	10 ppm
Odor	No pronounced odor
Carbon dioxide	1,000 ppm

needed. It is recommended that the evaluation be conducted by a knowledgeable person not directly associated with the program instead of the respiratory protection program administrator. The outside individual brings a new set of eyes in an attempt to prevent overlooking deficiencies.

As a minimum records and certifications regarding medical evaluations, fit testing, inspection of emergency use respirators, replacement of filters and sorbents for ensuring good air quality from compressors, air sampling, and objective data used to establish chemical cartridge changes schedules must be maintained.

A program evaluation checklist covering the entire program should be prepared and updated as required. There must be an effective means for correcting any defects found during the evaluation. A record should be kept of the findings along with plans and target dates for correction of deficiencies or problems, and actual date completed.

HISTORY OF RESPIRATOR REGULATIONS AND APPROVALS

After enactment of the Occupational Safety and Health Act (OSHAct), the National Institute for Occupational Safety and Health (NIOSH), and the U.S. Bureau of Mines (USBM) jointly promulgated 30 *CFR* Part 11, which prescribed approval procedures, established test requirements, and set fees for obtaining joint approval of respirators. Over the years, government reorganization has resulted in transfer of the approval functions to NIOSH. NIOSH has been named as the testing, approving, and certifying agency for respirators. When NIOSH took over the sole responsibility for respirator approval, the approval requirements were changed and moved to 42 *CFR* Part 84 (42 *CFR* 84). The respirator approvals are issued by NIOSH with the exception of self-contained self-rescuers. These devices are used for self-rescue from mines. NIOSH and the Mine Safety and Health Administration (MSHA) jointly approve them.

The NIOSH Testing and Certification Laboratory has the following responsibilities:

- ➢ To publish certification requirements
- ➢ To test and certify products meeting those requirements
- ➢ To publish lists of certified products
- ➢ To audit respirator manufacturer's facilities to determine the acceptability of their quality-assurance programs
- ➢ To sample products from the open market and test them for continued conformance to certification requirements
- ➢ To perform research on the development of new test methods and requirements for product improvement where necessary to ensure worker protection

All NIOSH-approved respiratory protection devices have an approval label similar to that shown in Figure 22–3.

Voiding an Approval

Once a NIOSH-approved respirator has been selected, the user should become acquainted with the limitations of the device as set forth in the approval (Figure 22–3). The approval will be void if the device is used in conditions beyond the limitations set by NIOSH or those established by the manufacturer. The user should also guard against any alteration being made to the device. All parts, filters, canisters, cartridges, or anything else not specifically intended to be used on the device by NIOSH or the manufacturer will void the existing approval. If there is any question concerning parts, alteration, or limitation of the device, always checks with the manufacturer. The employer should take care so as not to knowingly void the approval for a piece of equipment.

NIOSH has the authority to purchase and test respiratory-protective devices on the open market as a continuing check on manufacturers' quality-assurance standards and adherence to approvals. Manufacturers may not institute design changes of the device or its components without obtaining an extension of an existing approval or resubmitting a device for a new approval.

Passage of the OSHAct affected respiratory protection in another way besides leading to NIOSH approvals. Shortly after OSHA was established, OSHA promulgated a standard regulating the use of respiratory-protective devices. In January 1998, OSHA revised its respiratory protection standard. This standard, 29 *CFR* 1910.134, "Respiratory Protection," established the requirements for a respiratory protection program (see Addendum). These program requirements are essentially identical to those discussed earlier in this chapter. NIOSH and OSHA requirements are interrelated in that OSHA requires approved respirators to be used and NIOSH certification establishes limitations on the use of the respirators; OSHA regulates the use, whereas NIOSH regulates the design and performance of respiratory-protective equipment. OSHA sometimes allows for use of respirators that are different from the NIOSH use limitations. NIOSH, however, sometimes makes recommendations regarding respiratory-protective equipment use that may be different than OSHA requirements. These recommendations do not change or replace OSHA standards.

In addition to 29 *CFR* 1910.134, OSHA has promulgated other standards that address respiratory protection requirements that may be more specific to certain situations or more stringent. These include the ventilation standard for abrasive blasting respirator use requirements, the standards for hazardous waste operations and emergency response, permit-required confined spaces, and the fire brigade, as well as the various substance specific standards such as asbestos, lead, benzene, and cadmium. This is not a comprehensive list; OSHA is continually promulgating new substance-specific standards. Consult the appropriate OSHA standards covering the industries or operations in question.

CLASSES OF RESPIRATORS

Respiratory-protective devices can be described based on their capabilities and limitations and placed in three classes:

3M
St. Paul, Minnesota, USA
1-800-243-4630

COMBINATION OPEN-CIRCUIT, PRESSURE-DEMAND, ENTRY AND ESCAPE SCBA OR OPEN-CIRCUIT, PRESSURE-DEMAND SUPPLIED AIR RESPIRATOR

THE 2000 SYSTEMS ARE APPROVED ONLY IN THE FOLLOWING CONFIGURATIONS

		RESPIRATOR COMPONENTS																																			
	Component	Alternate Facepiece		Alternate Faceshield		Alternate Backpack/Harness		Pneumatics / Regulator	Alternate Airline Connection Kit				Alternate Cylinder and Valve			Alternate Hose Assembly														Demand Valve	Accessories							
NIOSH Approval Number TC-	Protection / Part Number	370-06-00	7800S-BA	7998	7988	361-18-00	361-30-00	362-16-00	362-16-81	362-16-81HK	362-16-81FS	362-16-81SC	366-03-00	366-04-00	366-22-00	367-01-02HK1	367-02-02HK1	367-03-02HK1	367-01-02FS1	367-02-02FS1	367-03-02FS1	367-01-02SC1	367-02-02SC1	367-03-02SC1	367-01-02HA1	367-02-02HA1	367-03-02HA1	W9435/S22-25, 50, 100	W9435Y/S22-25, 50, 100	363-07-00	7883	370-06-07	370-06-09	7894	7925	7915	7993	Cautions and Limitations[2]
13F-0279	2216 PSI 30 MIN SC/PD	X	X	X	X	X	X	X					X	X	X															X	X	X	X	X	X	X	X	JMNOS
13F-0280	2216 PSI 30 MIN SC/SA/PD	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	DEJMNOS

1 Protection
PD - Pressure Demand
SA - Supplied Air
SC - Self Contained

2 Cautions & Limitations
D - Air-line respirators can be used only when the respirators are supplied with respirable air meeting the requirements of CGA G-7.1 Grade D or higher quality.
E - Use only the pressure ranges and hose lengths specified in the User's Instructions.
J - Failure to properly use and maintain this product could result in injury or death.
M - All approved respirators shall be selected, fitted, used, and maintained in accordance with MSHA, OSHA, and other applicable regulations.
N - Never substitute, modify, add, or omit parts. Use only exact replacement parts in the configuration as specified by the manufacturer.
O - Refer to User's Instructions, and/or maintenance manuals for information on use and maintenance of these respirators.
S - Special or critical User's Instructions and/or specific use limitations apply. Refer to User's Instructions before donning.

1/22/99

Figure 22–3. A typical approval label that accompanies each NIOSH-approved respirator. This label is for a self-contained breathing apparatus. The user should make sure the limitations of the device are understood. (Courtesy 3M.)

air-purifying, atmosphere-supplying, and combination air-purifying and atmosphere-supplying devices.

Air-Purifying Devices

The air-purifying device cleanses the contaminated atmosphere. Ambient air passes through an air-purifying element that can remove specific gases and vapors, aerosols, or a combination of these contaminants. This type of device is limited in its use to those environments where there is sufficient oxygen to support life and the contaminant's airborne concentration level is within the maximum use concentration of the device. The useful life of an air-purifying device is limited by the concentration of the air contaminants, the breathing rate of the wearer, temperature and humidity levels in the workplace, and the removal capacity of the air-purifying medium.

AEROSOL-REMOVING RESPIRATORS

Aerosol removing respirators offer respiratory protection against airborne particulate matter, including dusts, fibers, mists, and fumes, but they do not protect against gases, vapors, or oxygen deficiency. These respirators are equipped with filters to remove aerosols (particles) from the air. The filter may be a replaceable part or a permanent part of the respirator. They consist essentially of a facepiece, either quarter-face (above the chin), half-face (under the chin) (Figure 22–1a), or full-face design (Figure 22–4). Directly attached to the facepiece is one of several types of filters made up of a fibrous material that removes the particles by trapping them as air is inhaled through the filter. Particulate respirators where the filter is a permanent part of the respirator or the entire facepiece is composed of the filtering medium, are sometimes referred to as disposable respirators and more recently as filtering facepiece respirators.

Figure 22–4. A full facepiece respirator with replaceable P100 particulate filters. The viewing lens has been adapted to accommodate a welding lens for welding applications. A welding shroud covers the full facepiece and exposed skin for skin protection. (Courtesy 3M.)

There are many classes of filter respirators specifically designed for airborne particulate matter. Although a single particulate respirator can be made to provide effective protection against all aerosols, in most cases, it would be too expensive and perhaps too cumbersome for the great majority of users. There are potentially nine classes of respirators allowed by 42 *CFR* 84. The filter classes are designed for different types of aerosols, use times, and filter efficiency levels. Therefore, proper filter selection depends on knowledge of the material and the work conditions.

In these fibrous filters, various filtration mechanisms are at work. These filtration mechanisms include particle interception, sedimentation, impaction, and diffusion. In addition to these mechanical mechanisms some filters will also use electrostatic attraction. The filtration mechanisms work together in every filter to some degree, as the filter manufacturer attempts to make an efficient filter with low breathing resistance. The exact contribution of each mechanism depends on flow rate and particle size.

In *interception capture,* the particles do not deviate from their original streamline of air (Figure 22–5). As the airstreams approach a fiber lying perpendicular to their path, they split and compress in order to flow around the fiber. The airstreams rejoin on the other side of the fiber. If the center of a particle in these airstreams comes within one particle radius of the fiber, it contacts the fiber surface and is captured. As particle size increases, the probability of interception increases.

Sedimentation capture is due to the effect of gravity on the particle; therefore, the flow rate through the filter must be low (Figure 22–6). It is most significant for large particles, for example, larger than 3 μm.

Particles with sufficient inertia cannot change direction sufficiently to avoid the fiber. As the airstreams split and change direction suddenly to go around the fiber, these particles are captured due to *impaction* on the surface of the fiber (Figure 22–7). A particle's size, density, speed, and shape determine its inertia.

Diffusion is particle movement due to air molecule bombardment and is important only for smaller particles (Figure 22–8). The particles can randomly cross the airstreams and encounter a filter fiber. This random motion is dependent on particle size and temperature. For example, as particle size decreases, diffusive activity of the particle increases. This increases the chance of capture. A lower flow rate through the filter also increases the chance of capture as the particle spends more time in the area of the fiber.

In *electrostatic capture* the charged particles are attracted to filter fibers or regions of the filter fiber having the opposite charge. Uncharged particles may also be attracted depending on the level of charge imparted on the filter fiber. This mechanism aids the other removal mechanisms, especially interception and diffusion. These filter types use electrical charges to enhance their mechanical filtering capabilities. In the past two types of electrostatic materials were used in respirator filters in the United States, resin wool and electrets. With the

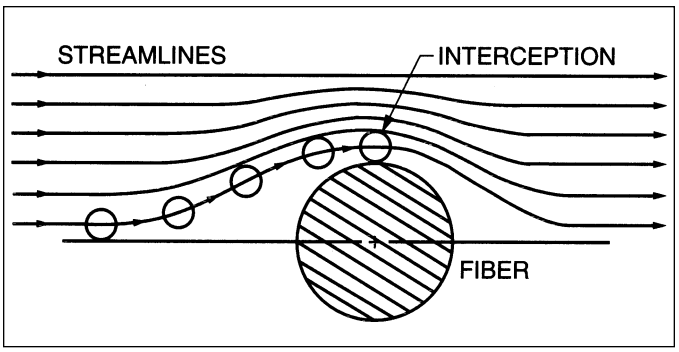

Figure 22–5. Interception capture mechanism.

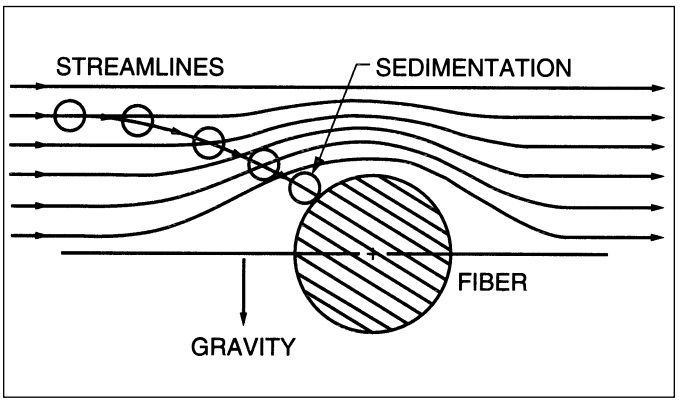

Figure 22–6. Sedimentation capture mechanism.

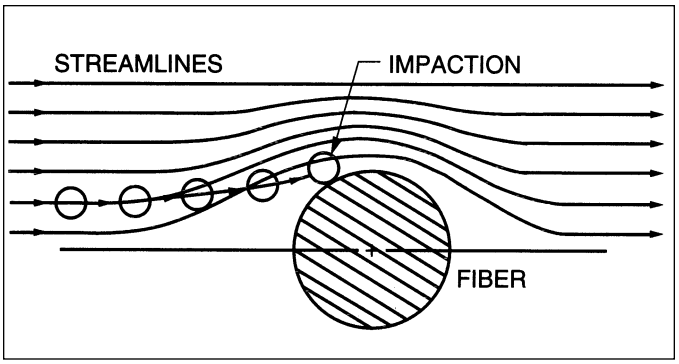

Figure 22–7. Impaction capture mechanism.

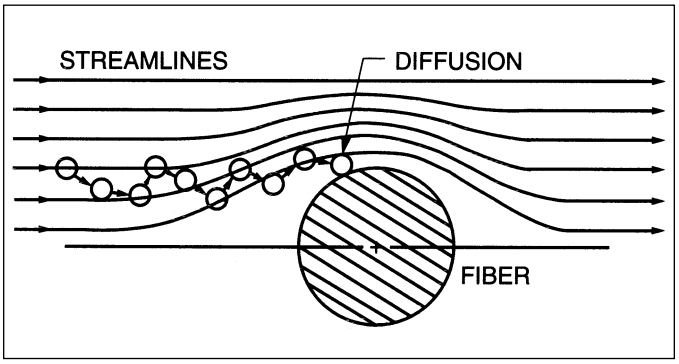

Figure 22–8. Diffusion capture mechanism.

revision of the nonpowered particulate respirator approval tests, NIOSH-approved respirators with resin wool filters no longer exist. All electrostatic filters are of the electret type.

Electret fibers are a recent development in filtration technology. Over the last several years, they have undergone many improvements. Electret fibers are plastic fibers that have a strong electrostatic charge permanently embedded into their surface during processing. They maintain a positive charge on one side of the fiber and a negative charge of equal magnitude on the opposite side of the fiber (Figure 22–9). Both charged and uncharged particles will be attracted to electret fibers. Charged particles are attracted to the parts of the fiber which have an opposite charge. Uncharged particles have equal internal positive and negative charges. The strong electrostatic forces of the electret fibers polarize these charges, inducing a dipole within the particle, and the particle is then attracted to the fiber by a polarization force. Long-term environmental testing of electret filters using elevated temperatures and humidity indicated they were not affected by exposure to these conditions.

The exact combination of capture mechanisms depends upon several factors. Generally, large heavy particles are removed by impaction and interception; large, light particles are removed by diffusion and interception. Diffusion removes very small particles (Figure 22–10). When the fiber used in the explanation of the capture mechanisms is joined by other fibers to create a filter maze of certain average porosity and thickness, the different filtration mechanisms will combine at different particle sizes to affect total filtration performance and efficiency. The capture mechanisms of sedimentation, interception, and inertial impaction combine

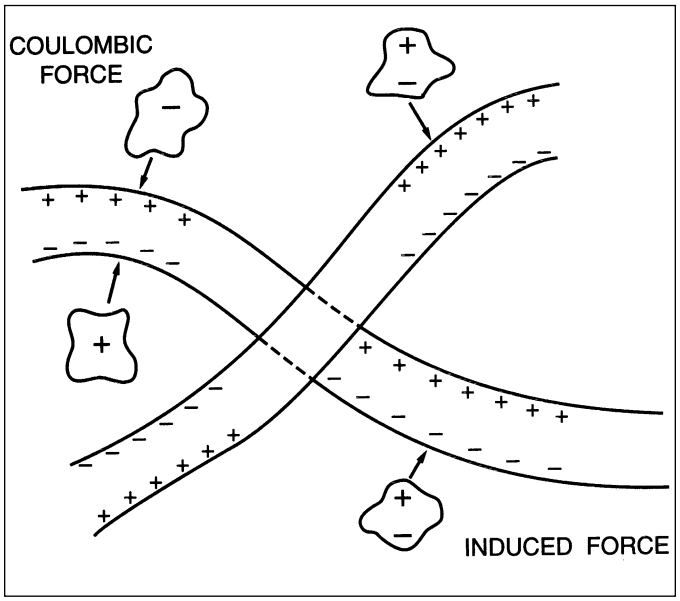

Figure 22–9. Long-range attraction of particles by the permanently charged electret fibers. A coulombic force attracts the two charged particles on the left, while a polarization force attracts the two uncharged particles on the right.

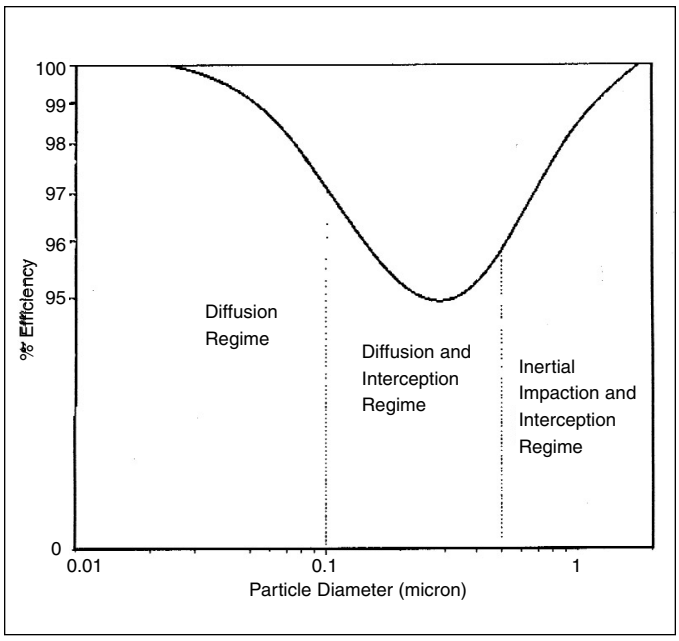

Figure 22–10. Filter efficiency vs. particle size with mechanical filtration mechanisms identified.

effectively to remove nearly all particles sized above 0.6 µm. Additionally the low flow rates through respirator filters of only a few centimeters per second let diffusion play its part very effectively for particles below 0.1 µm.

However, between these two particle size regions (0.1 to 0.6 µm), diffusion and impaction are not as effective and a minimum filtration efficiency exists as shown in Figure 22–10. The lowest point on this curve is called the most penetrating particle size and can be determined empirically in the laboratory. The most penetrating size range can vary with filter design and flow rate. The addition of an electrostatic charge to the fibers improves the filtering ability in this range by increasing the capture efficiency at the "most penetrating particle size." Most respirator filters have a "most penetrating particle size" between 0.2 and 0.4 µm. This is the basis for the widely used dioctyl phthalate (DOP) test for particulate filters using a 0.3-µm particle. The filter efficiency for good filters will always be much better at any particle size other than the "most penetrating particle size." Because a respirator filter has measurable penetration of particles in the 0.2 –0.4 µm range, it is easy to forget the fact that anywhere else in the wide range of particle size in the workplace, filtration efficiency is essentially 100 percent. For the filter in Figure 22–10, the penetration at the "most penetrating particle size" is around five percent, while at 1 µm the penetration is only about one percent. It is the reduction of the entire actual work environment particulate challenge in particle number or mass that is important to protecting the worker. Table 22–B shows overall mass efficiency for a filter with five-percent penetration at the most penetrating size, a class 95 filter. Note that the overall efficiency is much greater than 95 percent for the industrial aerosols shown.

The most desirable compromise must be worked out for each filter classification with respect to filter-surface area, resistance to breathing, efficiency in filtering particles of specific size ranges, and the time to clog the filter. Filters may be made of randomly laid nonwoven fiber materials or fibrous glass that may be loosely packed in a filter container or made into a flat sheet of filter material that is pleated and placed in a filter container. Pleating is a way in which the filter surface area is increased, which can improve filter loading, and lower breathing resistance.

NIOSH certifies nine classes of filters. These filters may be either replaceable or an integral part of the respirator. At the end of service the filters are discarded or, in the case where they are a permanent part of the respirator, the entire respirator is disposed. The replaceable filters may be used on either a half-facepiece or full-facepiece respirator. The nine classes of filters are divided into three filter series, N, R, and P. Because some oils and oil-like materials may affect some filter materials so that the filter efficiency (not the filter) is degraded with use, three categories with different degrees of resistance to filter efficiency degradation were established.

Table 22–B. ***Mass Efficiency for Class 95 Filters by Industry***

Industry[A]	*Size (MMAD)*[B]	*GSD*	*% Efficiency*[C]
Lead smelter, sintering	11	2.4	100
Lead smelter, furnace	3.3	15.7	99.67
Brass foundry, pouring	2.1	10.3	99.65
Brass foundry, grinding	7.2	12.9	99.73
Woodworking, fine	1.3	2.7	99.70
Woodworking, coarse	33.1	2.6	100
Wood model shop	7.2	1.4	100
Spray painting, lacquer	6.4	3.4	99.95
Spray painting, enamel	5.7	2.0	100

[A] Adapted from Hinds WC, Bellin P. Effect of facial-seal leaks on protection provided by half-mask respirators, *Appl Ind Hyg* 3(5):158–164, 1988.

[B] MMAD=mass median aerodynamic diameter.

[C] Calculated at a moderate work rate, 30 Lpm.

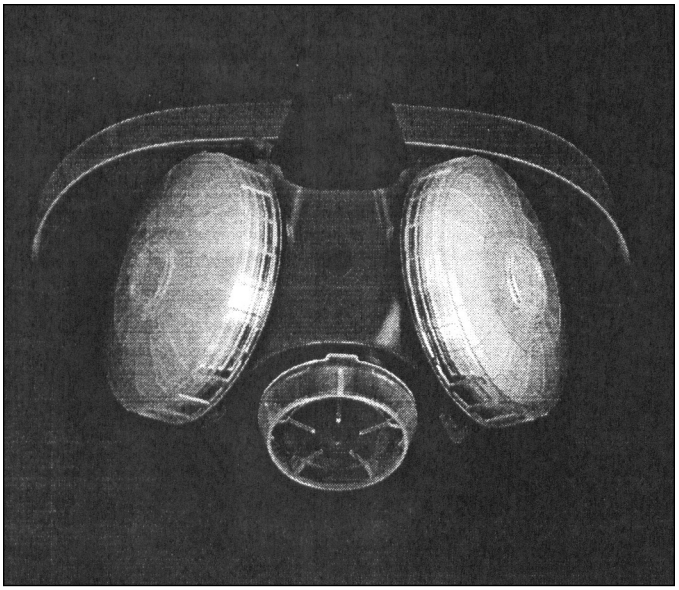

Figure 22–11a.

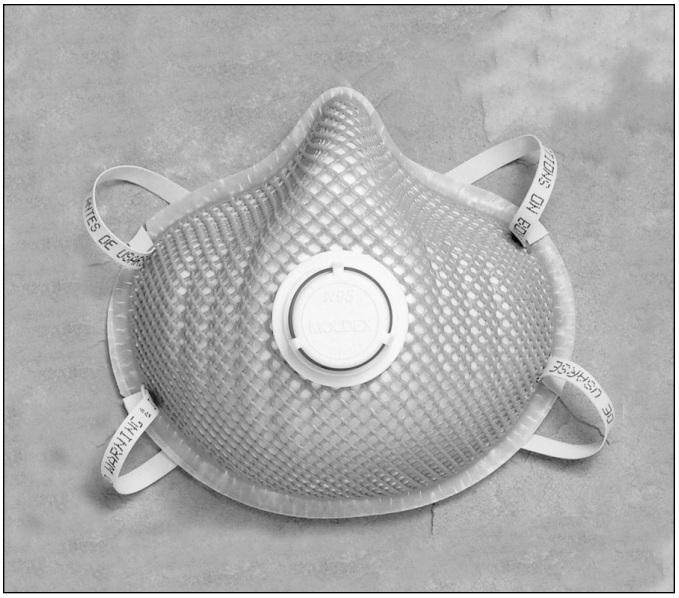

Figure 22–11b. a. Half-facepiece respirator with replaceable N95 particulate filters. (Courtesy 3M.) b. Disposable half facepiece N95 particulate filter respirator. Also referred to as a filtering facepiece respirator. (Courtesy Moldex Metric, Inc.)

Each filter series has three levels of filter efficiency: 95 percent, 99 percent, and 99.97 percent.

- ➢ *N-Series Filters.* These filters are restricted to use in atmospheres free of oil aerosols. They may be used for any solid or liquid airborne particulate hazard that does not contain oil. Generally these filters should be used and reused subject only to conditions of hygiene, damage, and increased breathing resistance.
  - ➢ N95 Particulate Filter: This N-Series filter is at least 95 percent efficient when tested with ~0.3 μm NaCl aerosol. Many of the so-called filtering facepiece respirators have N95 particulate filter approvals. However, this respirator category is not restricted to filtering facepiece respirator types. These filters may also be approved for use as replaceable filters on half-facepieces and full-facepieces (Figure 22–11).
  - ➢ N99 Particulate Filter: This N-Series filter is at least 99 percent efficient when tested with ~0.3 μm NaCl aerosol.
  - ➢ N100 Particulate Filter: This N-Series filter is at least 99.97 percent efficient when tested with ~0.3 μm NaCl aerosol (Figure 22–12).
- ➢ *R-Series Filters.* A filter intended for the removal of any particle including oil-based liquid aerosol. They may be used for any solid or liquid airborne particulate hazard. If the atmosphere contains oil, the R-Series filter should be used only for a single shift (or for eight hours of continuous or intermittent use). In the approval tests these filters are loaded with 200 mg of the test aerosol and filter efficiency is then determined. It is not known what happens beyond this loading point, but at 200 mg level the filter efficiency is still equal to or greater than that required for certification at the indicated level.
  - ➢ R95 Particulate Filter: This R-Series filter is at least 95 percent efficient when tested with ~0.3 μm DOP (dioctyl phthalate) aerosol (Figure 22–13).
  - ➢ R99 Particulate Filter: This R-Series filter is at least 99 percent efficient when tested with ~0.3 μm DOP (dioctyl phthalate) aerosol.
  - ➢ R100 Particulate Filter: This R-Series filter is at least 99.97 percent efficient when tested with ~0.3 μm DOP (dioctyl phthalate) aerosol.
- ➢ *P-Series Filters.* A filter intended for the removal of any particle including oil-based liquid aerosol. They may be used for any solid or liquid airborne particulate hazard. These filters have been tested to a point where filter efficiency was not degrading. Consequently they have longer

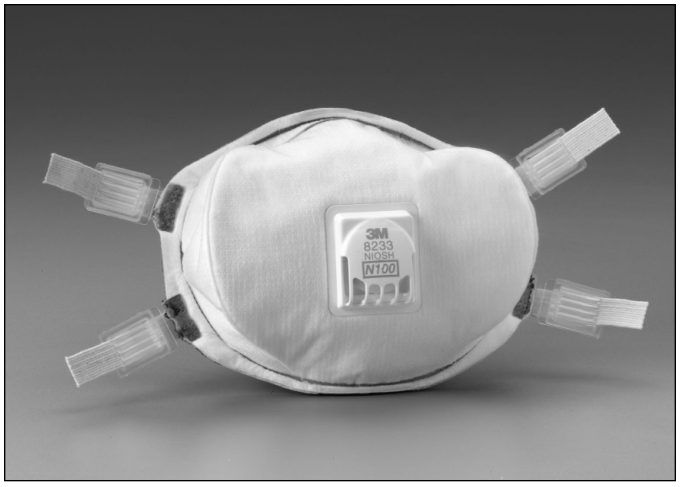

Figure 22–12. Disposable (filtering facepiece) N100 particulate filter respirator. (Courtesy 3M.)

Figure 22–13. Filtering facepiece R95 particulate filter respirator. (Courtesy 3M.)

use periods than the R-series filters. Because no filter will last forever, NIOSH requires respirator manufacturers to put a time restriction for all P-series filters. Consult the manufacturer's instructions for specific guidance on how long to use the filter before it should be replaced.

- ➢ P95 Particulate Filter: This P-Series filter is at least 95 percent efficient when tested with ~0.3 µm DOP (dioctyl phthalate) aerosol.
- ➢ P99 Particulate Filter: This P-Series filter is at least 99 percent efficient when tested with ~0.3 µm DOP (dioctyl phthalate) aerosol.
- ➢ P100 Particulate Filter: This P-Series filter is at least 99.97 percent efficient when tested with ~0.3 µm DOP (dioctyl phthalate) aerosol. This filter or its container is magenta colored (Figures 22–1a, 22–4).

It is difficult to perceive the difference between aerosol filters visually. Therefore it is important to read the NIOSH approval label or filter designation to identify against which aerosols (oils or non-oils) the filter should be used. Oil has never been defined by a regulatory agency. The following definition may be helpful, however, in deciding whether the material should be considered an oil.

Oil: Any of numerous mineral, vegetable, and synthetic substances and animal and vegetable fats that are generally slippery, combustible, viscous, liquid, or liquefiable at room temperatures, soluble in various organic solvents such as ether but not in water.

While there are differences in stated filter efficiencies at the most penetrating particle size, it is important to note that industrial aerosols are not predominantly in this size range (Table 22–C). When NIOSH established these filter categories they stated that all of these filters would be effective against any particle size. Particle size is not a major concern when selecting one of these filters. Generally speaking, however, the higher the filter efficiency the greater the breathing resistance. Breathing resistance can greatly affect the comfort of the wearer and affect the amount of time the worker wears the respirator (see wear time discussion).

Table 22–C. *Aerosol Size Distributions for Various Industrial Operations*

Operation	*MMAD, µm*	*GSD*
Mining		
Open pit, general environment	2.5	4.7
Open pit, in cab	1.1	2.4
Coal mine, continuous miner	4.6	2.5
Coal mine, continuous miner	15.0	2.9
Coal mine, continuous miner	17.0	3.1
Coal mine, other operations	11.5	2.8
Oilshale mine	2.8	3.5
Smelting and Foundry		
Lead smelter, sintering	11.0	2.4
Lead smelter, furnace	3.3	15.7
Brass foundry, pouring	2.1	10.3
Brass foundry, grinding	7.2	12.9
Iron foundry, general environment	2.8	5.1
Iron foundry, general environment	16.8	4.4
Be-Cu foundry, furnace	5.0	2.4
Nuclear fuel fabrication	2.1	1.6
Non-mineral Dust		
Bakery	12.1	4.2
Cotton gin	47.1	2.7
Cotton mill	7.6	4.0
Swine confinement building	9.6	4.0
Woodworking, machining, sanding		
fine mode	1.3	2.7
coarse mode	33.1	2.6
Wood model shop	7.2	1.4
Metal Fume		
SMA (stick) welding	0.38	1.8
MIG welding	0.48	2.3
Lead fume (0_2-Nat. gas)	0.37	2.1
Mist and Spray		
Pressroom, ink mist	27.4	4.3
Spray painting, lacquer	6.4	3.4
Spray painting, enamel	5.7	2.0
Aerosol spray products	6.4	1.8
Other		
Forging	5.5	2.0
Refinery, fluid catalytic cracker	6.2	2.4
Cigarette smoke (diluted)	0.4	1.4
Pistol range	2.6	3.8
Diesel exhaust (age = 5-600 s)	0.12	1.4

(Adapted from Hinds WC, Bellin P. Effect of facial-seal leaks on protection provided by half-mask respirators, *Appl. Ind. Hyg* 3(5):158–164, 1988.)

Figure 22–14. Half-facepiece chemical cartridge respirator with interchangeable cartridges affords protection against light concentrations of organic vapors and certain gases. (Courtesy 3M.)

GAS/VAPOR REMOVING RESPIRATORS

These air-purifying respirators protect against certain gases and vapors by using various chemical filters to purify the inhaled air (Figure 22–14). They differ from aerosol filters in that they use cartridges or canisters containing sorbents, generally carbon, to remove harmful gases and vapors. The cartridges may be replaceable or the entire respirator may be disposable. Sorbents are granular, porous materials that interact with the gas or vapor molecule to clean the air. In contrast to aerosol filters, which are effective to some degree no matter what the particle, cartridges and canisters are designed for protection against specific contaminants (such as ammonia gas or mercury vapor) or classes of contaminants (such as organic vapors). Table 22–D identifies the various types of chemical cartridges approved by NIOSH. Activated carbon is commonly used for removal of organic vapors. Activated carbon is a carbon material that has its surface greatly enhanced using heat and steam. The most common starting carbon materials for respirator cartridges are coconut and coal. Activated carbon has an extensive network of internal pores of near molecular dimensions and consequently large internal surface areas. The typical range of surface area is 1,000–2,000 m^2/gram of carbon.

Organic vapors are removed by the process of adsorption. *Adsorption* is the adherence of gas or vapor molecules to the surface of the activated carbon. The attractive force between the activated carbon and the chemical molecule is a relatively small, weak physical force. The strength of the attraction depends in part on the chemical. Generally, organic vapors of molecular weight (MWT) greater than 50 or boiling points (BP) greater than 70 C are effectively adsorbed by activated charcoal. For gases and vapors that would otherwise be weakly adsorbed, sorbents can be impregnated with chemical reagents to make them more selective. Examples are activated charcoal impregnated with iodine to remove mercury vapor or with metal salts like nickel chloride to remove ammonia gas or with copper oxides and metal sulfates or salts of sulfamic acids to remove formaldehyde.

Impregnated activated carbon removes specific gas and vapor molecules by chemisorption. *Chemisorption* is the formation of bonds between molecules of the impregnant and the chemical contaminant. These bonds are much stronger than the attractive forces of physical adsorption. Both removal mechanisms are essentially 100-percent efficient until the sorbent's capacity is exhausted. At this point "breakthrough" occurs as the contaminant passes through the cartridge or canister and into the respirator.

Cartridges and canisters should be changed before breakthrough occurs. To do this cartridge change schedules must be established based on the expected service life time for the particular workplace environment that the cartridge is being used in. When the breakthrough point is reached, the worker should exit to a clean area and replace the cartridges, canister, or respirator. Cartridges are similar to canisters. The basic difference is the volume of sorbent, not the function. Canisters have the larger sorbent volume.

Table 22–D. ***Chemical Cartridge Types and Removal Mechanisms***

Chemical Cartridge Type	*Removal Mechanism*
Organic Vapors	Adsorption
Acid Gases[1]	Chemisorption
Organic Vapors / Acid Gases	Adsorption / Chemisorption
Ammonia & Methylamine	Chemisorption
Formaldehyde	Chemisorption
Multiple Gases & Vapors[2]	Organic vapors via adsorption/others via chemisorption
Mercury Vapor[3]	Chemisorption
Hydrogen Fluoride	Chemisorption and/or chemical reaction

[1] Acid gases includes chlorine, chlorine dioxide, hydrogen chloride, hydrogen fluoride, hydrogen sulfide, and sulfur dioxide.

[2] May vary with the manufacturer. May include organic vapors, acid gases, ammonia, methylamine, and formaldehyde.

[3] Usually have an end-of-service life indicator.

Figure 22–15a.

Figure 22–15b. Gas masks provide longer service life than chemical cartridge respirators for many commonly encountered vapors and gases. a: Chin-style gas mask. b. Back-mounted gas mask. (Courtesy Scott Aviation Health and Safety Products.)

Service life of these respirators depends on the following factors: quality and amount of sorbent; packing uniformity and density; exposure conditions, including breathing rate of the wearer, relative humidity, temperature, contaminant concentration, the affinity of the gas or vapor for the sorbent, and the presence of other gases and vapors. (Generally, high concentrations, a high breathing rate, and humid conditions adversely affect service life.) Table 22–E shows various chemical cartridge breakthrough times for different organic gases and vapors. Although the organic vapor cartridge is approved by testing against carbon tetrachloride, the cartridge may last a longer (as with butanol) or a much shorter (as with methanol) time period than when compared to the test agent. Hence, an organic vapor cartridge may be recommended for use against butanol, but not for methanol (MWT < 50; BP < 70 C), even though both compounds are classified as organic vapors.

Relative humidity. Relative humidity (RH) greater than 50 percent (especially greater than 65%) can have a dramatic effect on service life of organic vapor chemical cartridges. The effect of relative humidity on service life of organic vapor cartridges will depend on the relative humidity level, the chemical concentration, volatility of the chemical, and the chemical's miscibility (ability to dissolve) in water. For chemicals with low volatility, such as styrene, the effect of high relative humidity is small. For more volatile chemicals,

Table 22–E. *Organic Vapor Chemical Cartridge Breakthrough Times for Various Chemicals*

Chemical	*Time to 1% (10 ppm) breakthrough (minutes)*[1]
Aromatics	
Benzene	73
Toluene	94
Xylene	99
Alcohols	
Methanol	0.2
Isopropanol	54
Butanol	115
2-Methoxyethanol	116
Chlorinated hydrocarbons	
Methyl chloride	0.05
Vinyl chloride	3.8
Dichloromethane	10
Trichloroethylene	55
Carbon tetrachloride	77
Perchloroethylene	107
Ketones	
Acetone	37
2-Butanone	82

1. Cartridges challenged with 1000 ppm of the respective chemical. Tested at 50 percent relative humidity, 22 C, and 53.3 L/min.

(Adapted from Nelson GE, Harder CA. *AIHA Journal* 35:391–410, 1974.)

the most significant RH effect is at low concentrations. The service life for cartridges using impregnated activated charcoal is not affected by relative humidity like the organic vapor cartridge. In fact, higher RH may actually increase the service life of cartridges with impregnated carbon, especially those for acid gases.

Migration. Since only weak physical forces hold the organic vapors on activated carbon, the process can be reversed. This is called *desorption*. Desorption is the process of an adsorbed material "letting go" from the activated carbon. Desorption can occur naturally during periods of nonuse or by the presence of another more strongly adsorbed substance displacing a less strongly adsorbed chemical (that is, a more volatile chemical). Generally, the more volatile the chemical the less strongly adsorbed, or the more likely it will undergo desorption. Desorption during storage or nonuse times can result in chemical migration. *Migration* is the movement of a previously adsorbed chemical through the chemical cartridge, even without air movement. Migration is mainly a concern only for organic vapor cartridges. Variables that appear to impact migration include:

- ➢ Volatility—the more volatile the chemicals, the greater the concern for migration
- ➢ Water vapor coadsorption—coadsorption (from use in atmospheres with high relative humidity [>50%]) can increase the migration effect
- ➢ Amount of material adsorbed onto the cartridge in the first use
- ➢ Storage time
- ➢ Vapor type

The potentials for desorption and migration makes reuse of organic vapor cartridges a concern. Desorption of very volatile contaminants can occur after a short period (hours) without use (for example, overnight). Partial use of the chemical cartridge and subsequent reuse could potentially expose the user to the contaminant. This is most significant for the most volatile and poorly retained organic vapors (for example, boiling point < 65 C). These chemicals are often classified as low boiling chemicals. However, a boiling point of 65 C is not a fine line between chemicals that migrate and those that do not. Chemicals with boiling points greater than 65 C can still migrate, but the nonuse period of concern may be longer than above. As the volatility decreases migration will become less of a concern.

The chemical bonds formed during chemisorption typically result in irreversible binding of the chemical contaminant to the impregnant. Migration is usually not a concern for these cartridges. Thus, reuse of chemical cartridges that work on the principle of chemisorption is not a problem.

Limitations. Chemical cartridges and canisters are limited to use in concentrations that are no greater than the assigned protection factor of the respirator times the occupational exposure limit. This is called the maximum use concentration (MUC). At one time, maximum use limits were included on the cartridge or canister. These have been removed by NIOSH; thus the maximum use concentration limits are dependent upon the respirator's assigned protection factor. This topic will be discussed later in this chapter. *Gas mask* is a term used often for a gas- or vapor-removing respirator that uses a canister. Although gas masks are limited by their assigned protection factor, they can be used for escape-only from atmospheres immediately dangerous to life or health (IDLH) which contain adequate oxygen to support life (≥19.5 % O_2). They must *never* be used for entry into an IDLH atmosphere.

Cartridge and canister replacement. Cartridges and canisters should be replaced under any one or more of the following conditions:

- ➢ If the end of service life indicator shows the specified color change
- ➢ As indicated by the change schedule
- ➢ If the shelf life is exceeded
- ➢ If an OSHA regulation specifies a disposal frequency (as with formaldehyde and benzene)

If a person is wearing a cartridge or canister that needs replacement, they should return to fresh air as quickly as possible. In addition, if uncomfortable heat in the inhaled air is detected or the wearer has a feeling of nausea, dizziness, or ill-being it is imperative they return to fresh air. (A properly operating cartridge or canister may become warm on exposure to certain gases or vapors, but a device that becomes extremely hot indicates that concentrations greater than the device's limits have been reached.)

COMBINATION AEROSOL FILTER/GAS OR VAPOR-REMOVING RESPIRATORS

These respirators use aerosol-removing filters with a chemical cartridge or canister for exposure to multiple contaminants or more than one physical form (for example mist and vapor) (Figure 22–1b). The filter is generally a permanent part of the canister, but can be either permanent or replaceable on the chemical cartridge. Replaceable filters are sometimes used because the filter and chemical cartridge are not exhausted at the same time (Figure 22–16). This allows for disposing only of the part that is in need of changing. Filters used in combination with cartridges must always be located on the inlet side of the cartridge. This way, any gas or vapor adsorbed onto a filtered particle is captured by the sorbent as it desorbs from the particle. The combination aerosol filter/gas or vapor-removing respirators most often used are for paint spray and pesticides.

POWERED AIR-PURIFYING RESPIRATORS

The air-purifying element of these respirators may be a filter, chemical cartridge, or canister. They protect against particles, gases and vapors, or particles and gases and vapors. The difference between these and the air-purifying respirators previously discussed is that the powered air-purifying respirator (PAPR) uses a power source (usually a bat-

Figure 22–16. Workers wearing combination chemical cartridge/N95 particulate filter respirator for protection from solvent vapors and mists and glass fibers in a fiberglass operation. (Courtesy 3M.)

tery) to operate a blower that passes air across the air-cleansing element to supply purified air to a respiratory inlet (mouth and nose) covering. To be certified as a powered air-purifying respirator by NIOSH, the blower must provide at least four cubic feet per minute (cfm) of air to a tight-fitting facepiece (half-face or full-facepiece) and at least 6 cfm to a loose-fitting helmet, hood, or facepiece. Figure 22–17 shows a powered air-purifying respirator with a full facepiece and Figure 22-18 shows one with a loose-fitting hood. The great advantage of the powered air-purifying respirator is that it usually supplies air at positive pressure, reducing inward leakage when compared to the negative pressure respirators. This is why they have a higher assigned protection factor than their negative pressure counterpart. It is possible, however, at high work rates to create a negative pressure in the facepiece, thereby increasing facepiece leakage. This can be reduced by fit testing tight-fitting powered air-purifying respirators. When 42 *CFR* 84 was promulgated, the PAPR filter classifications were not changed. However all of the 30 *CFR* 11 filters were eliminated except for the high efficiency filter. Today the only particulate filter available for PAPRs is the high efficiency filter. This filter is approved for all aerosols. It is designed for protection against dusts, fumes, and mists of materials having an occupational exposure limit *less* than 0.05 mg/m^3 or 2 mppcf. These filters are

Figure 22–17. A full facepiece powered air-purifying respirator with the motor and blower assembly mounted in the facepiece with a welding lens adapter. (Courtesy 3M.)

Figure 22–18. Powered air-purifying respirators with hoods or helmets can be worn by workers with beards and/or eyeglasses. (Courtesy 3M.)

Figure 22–19.
Continuous flow air-line respirators are used in conjunction with a compressor system. The manifold for connecting to the air source can be seen in the background. (Courtesy 3M.)

many times referred to as high efficiency particulate air (HEPA) filters or simply high efficiency filters.

The high efficiency refers to the filter test requirement they must meet. HEPA filters must be at least 99.97 percent efficient when tested against 0.3 µm dioctyl phthalate (DOP) particle. DOP is the test material for the filter. These filters do not undergo loading with the test aerosol. The labels for these filters may also state they can be used for particulate radionuclides. Radionuclides are materials that spontaneously emit ionizing radiation.

Atmosphere-Supplying Respirators

Atmosphere-supplying devices are the class of respirators that provide a respirable atmosphere to the wearer, independent of the ambient air. The breathing atmosphere is supplied from an uncontaminated source. The air source for an atmosphere-supplying respirator must conform to grade D requirements as specified in the Compressed Gas Association Standard, G-7.1-1997, *Commodity Specification for Air*. Table 22–A lists the air quality requirements for grade D breathing air. Atmosphere-supplying respirators fall into three groups: air-line respirators, self-contained breathing apparatus (SCBA), and combination air-line and SCBA.

AIR-LINE RESPIRATORS

Air-line respirators deliver breathing air through a supply hose connected to the wearer's facepiece or head enclosure. The breathing air is supplied through the hose from either a compressor or compressed air cylinders. If a compressor supplies air, it must be equipped with specific safety devices according to OSHA. Oil-lubricated compressors must have a high-temperature or carbon monoxide alarm, or both, to monitor carbon monoxide levels. If only high-temperature alarms are used, the air supply must be monitored at sufficient intervals to prevent carbon monoxide from exceeding 10 ppm in the breathing air. For compressors that are not oil-lubricated, the employer must ensure that the carbon monoxide level does not exceed 10 ppm in the breathing air. No specific alarms or methods are required. A flow control valve, regulator, or orifice is provided to govern the rate of airflow to the worker. Depending on the certification, up to 300 feet of air supply hose is allowable. Hose supplied by the

Table 22–F. ***Oxygen-Deficient Atmospheres Where Atmosphere-Supplying Respirators May Be Used***

Altitude (ft)	*Percent Oxygen (%O_2)*
Less than 3,001	16.0 - 19.5
3,001 - 4,000	16.4 - 19.5
4,001 - 5,000	17.1 - 19.5
5,001 - 6,000	17.8 - 19.5
6,001 - 7,000	18.5 - 19.5
7,001 - 8,000 [A]	19.3 - 19.5

[A] Above 8,000 feet the exception does not apply. Oxygen-enriched breathing air must be supplied above 14,000 feet.

(Reprinted from OSHA General Industry Standards, 29 *CFR* 1910.134)

respirator manufacturer along with recommended hose lengths and operating pressures must be used. The maximum permissible inlet pressure is 125 pounds per square inch (psig). The approved pressure range and hose length is noted in the operating instruction manual provided with each approved device (Figure 22–19).

These devices should only be used in non-IDLH atmospheres, or atmospheres in which the wearer can escape without the use of a respirator. This limitation is necessary because the air-line respirator is entirely dependent upon an air supply that is not carried by the wearer of the respirator. If this air supply fails, the wearer may have to remove the respirator to escape from the area. OSHA considers all oxygen-deficient atmospheres to be IDLH. However, OSHA has established an exception. Any air-line respirator may be used in oxygen deficient atmospheres if the employer can demonstrate that, under all foreseeable conditions, the oxygen concentration can be maintained within the ranges specified in Table 22–F. Another limitation is that the air hose limits the wearer to a fixed distance from the air supply source.

Air-line respirators operate in three modes: demand, pressure demand, and continuous flow. The respirators are equipped with half facepieces, full facepieces, helmets, hoods, or loose-fitting facepieces. Some of these respiratory inlet coverings may provide eye protection.

Demand. Demand air-line respirators are equipped with either half or full facepieces. They deliver airflow only upon inhalation. Due to their design, a negative pressure with respect to the outside of the respirator is created in the facepiece upon inhalation. These respirators are negative-pressure devices. While these respirators can still be found in worksites, they are not recommended if one is buying new respirators because the pressure-demand type is available. The pressure-demand air-line respirator is much more protective and the cost differential between the two is negligible.

Pressure demand. Pressure-demand air-line respirators are very similar to the demand type except that because of their design, the pressure inside the respirator is generally positive with respect to the air pressure outside the respirator during both inhalation and exhalation. This positive pressure means that when a leak develops in the face seal due to head movement, for example, the leakage of air would be outward. Thus they provide a higher degree of protection to the user. They also are available only with half and full facepieces (Figure 22–20). Such respirators are normally used when the air supply is restricted to high-pressure com-

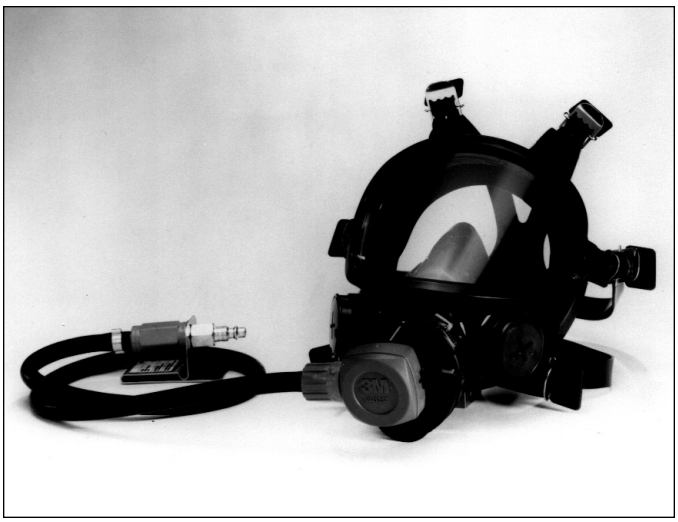

Figure 22–20. Pressure demand air-line respirators are used with compressed air supplied by a compressor or a cascade of compressed air cylinders. (Courtesy 3M.)

Figure 22–21. A continuous flow air-line respirator with a tight-fitting facepiece. (Courtesy 3M.)

Figure 22–22. A continuous flow air-line respirator with a helmet with a viewing lens adapter for welding. (Courtesy 3M.)

pressed air cylinders. A suitable pressure regulator is required to make sure the air pressure is reduced to the proper level for breathing.

Continuous flow. A continuous-flow unit has a regulated amount of air delivered to the facepiece or head enclosure and is normally used where there is an ample air supply such as that provided by an air compressor. These devices may be equipped with either tight-fitting or loose-fitting head enclosures. Those equipped with tight-fitting enclosures, a half or full facepiece, must provide at least 4 cfm measured at the facepiece (Figure 22–21). When loose-fitting helmets, hoods or facepieces are used, the minimum amount of air to be delivered is 6 cfm. In either case the maximum flow is not to exceed 15 cfm. Versions of these respirators may be designed for welding (Figure 22–22) or abrasive blasting (Figure 22–23). Respiratory-protective equipment designed for abrasive blasting is equipped to protect the wearer from impact of the rebounding abrasive material. A special hood may be used to protect the wearer's head and neck and shielding material may be used to protect the viewing windows of the head enclosures.

SELF-CONTAINED BREATHING APPARATUS

The self-contained breathing apparatus (SCBA) provides respiratory protection against gases, vapors, particles, and an oxygen deficient atmosphere. The wearer is independent of the surrounding atmosphere because the breathing gas is carried by the wearer. SCBA may be used in IDLH and oxygen-deficient atmospheres either as escape-only devices or for entry into and escape from these atmospheres. A full facepiece is most commonly used with these devices. Half facepieces, hoods, and mouthpieces are available on some units. There are two major types of SCBAs: closed circuit and open circuit.

Closed-circuit SCBA. In closed circuit SCBA (Figure 22–24) all or a percentage of the exhaled gas is scrubbed and rebreathed. Closed-circuit units have the advantage of lower weight for the same use duration as open-circuit devices. Units are available from 15 min to 4 h. Disadvantages include increased complexity (for example, a carbon dioxide scrubber is required in many of the units) and cost. Due to

Figure 22–23. Abrasive blasting continuous flow air-line respirator. (Courtesy 3M.)

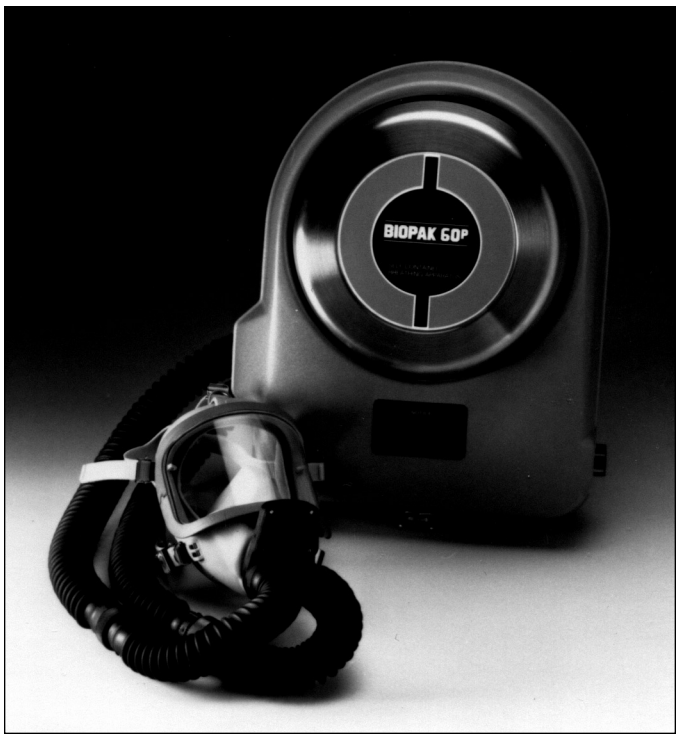

Figure 22–24. Closed circuit self-contained breathing apparatus designed for 60 minutes of service. (Courtesy Biomarine.)

Figure 22–26. Some self-contained breathing apparatus are designed for escape-only from hazardous atmospheres. (Courtesy MSA.)

Figure 22–25. Pressure demand self-contained breathing apparatus approved for oxygen deficient and immediately dangerous to life or health atmospheres. (Courtesy MSA.)

the design of many of the devices, the air supply can become quite warm because of rebreathing of the air. Closed-circuit SCBAs are available as both negative- and positive-pressure devices. They may be designed as a stored-oxygen system or an oxygen-generating system.

Stored oxygen systems supply oxygen compressed in cylinders or carried as a liquid. Oxygen is admitted to a breathing bag either as a continuous flow or controlled by a regulator governed by the pressure or degree of inflation of the bag. The wearer inhales from the bag, and exhales into it. Exhaled breath is scrubbed of carbon dioxide by a chemical bed, usually a caustic such as sodium hydroxide.

Oxygen-generating systems rely on chemical reactions to provide the needed oxygen. Water vapor from the exhaled breath reacts with a solid chemical, usually potassium superoxide, in a canister-size container that releases oxygen. Carbon dioxide is removed from the exhaled breath in the canister also.

Open-Circuit SCBA. In an open-circuit SCBA the exhaled breath is released to the surrounding environment rather than being recirculated. The breathing gas is generally compressed air. Typically they are designed to provide 30–60 min of service (Figure 22–25). According to OSHA regulation 1910.134, only full-facepiece, pressure-demand (positive-pressure) SCBAs are approved for IDLH atmospheres.

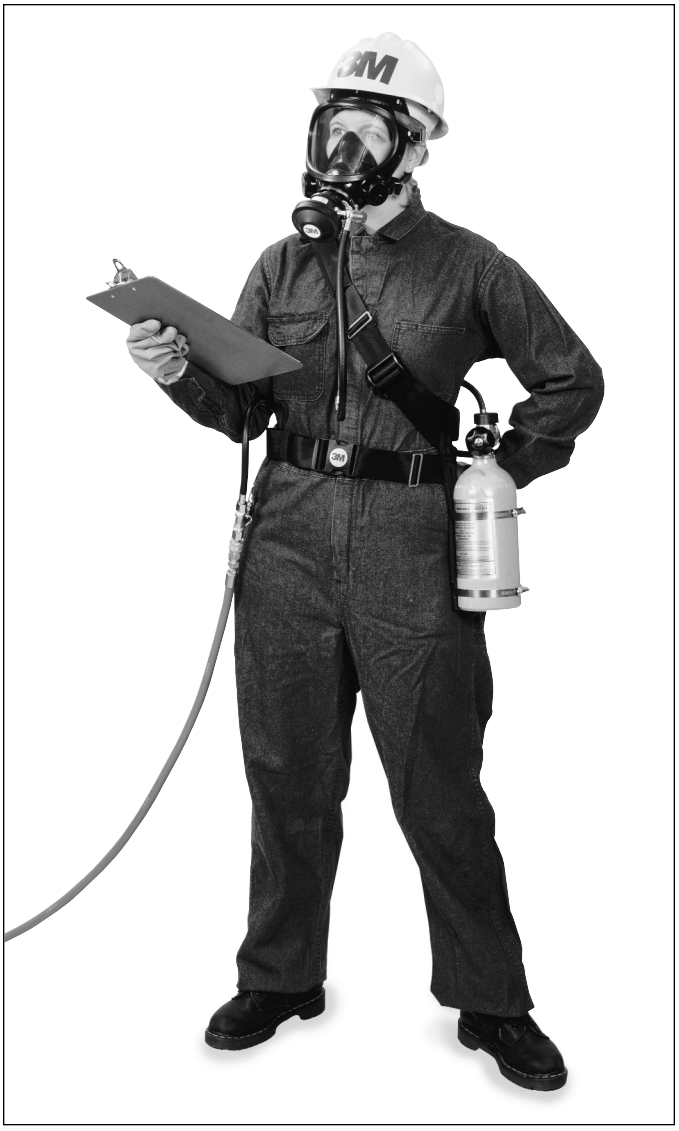

Figure 22–27. Combination self-contained breathing apparatus and air-line respirators can be connected to an external air supply for working in a hazardous atmosphere and still allowing for escape without removing the respirator. (Courtesy 3M.)

Escape SCBA. Some SCBAs are designed for escape only (Figure 22–26). They are similar in design to the types described above, except that the use duration tends to be shorter, typically 5, 7, or 10 min. Units approved for escape only may not be used to enter into a hazardous atmosphere. The fact that they are certified for escape only means that assigned protection factors have not been established for this category of respirator.

THE COMBINATION SELF-CONTAINED BREATHING APPARATUS (SCBA) AND AIR-LINE RESPIRATOR

These units are air-line respirators with an auxiliary self-contained air supply combined into a single device (Figure 22–27). (An auxiliary SCBA is an air supply, independent of the one to the air-line respirator, that allows a person to evacuate a contaminated area.) Because they have escape provisions, these devices are usable in IDLH and oxygen-deficient atmospheres. The auxiliary air supply can be switched to in the event the primary air supply fails to operate. This allows the wearer to escape from the IDLH atmosphere.

An advantage of these devices is they can be used in situations requiring extended work periods where the self-contained air supply alone does not provide sufficient time. In this situation, the wearer may connect to an air line to provide longer service time. The longer service life and smaller SCBA cylinder make these devices particularly convenient for use in confined spaces.

The auxiliary self-contained air supply may be NIOSH-approved in one of two categories: 3, 5, or 10-min service time or for 15 min or longer. If the SCBA portion is rated for a service life of 3, 5, or 10 min, the wearer must use the air line during entry into a hazardous atmosphere; the SCBA portion is used for emergency egress only. When the SCBA is rated for service of 15 min or longer, the SCBA may be used for emergency entry into a hazardous atmosphere (to connect the air line) provided not more than 20 percent of the air supply's rated capacity is used during entry. This allows for enough air for egress when the warning device indicates a low air supply.

The combination SCBA/air-line respirators may operate in demand, pressure-demand or continuous-flow modes. These devices use the same principles as the respective air-line respirator. Demand mode is not recommended.

Combination Air-Purifying and Atmosphere-Supplying Devices

Another type of respirator is gaining in popularity. It is a combination of an air-line respirator and an auxiliary air-purifying attachment, which provides protection in the event the air supply fails (Figure 22–28). NIOSH has approved combination air-line and air-purifying respirators with the air line operating in either continuous-flow or pressure-demand flow. These respirators can be used in either an air-purifying or air-line mode. The most popular versions are ones in which the air-purifying element is a class 100 filter, but devices are available with complete arrays of chemical cartridges as well.

These respirators have additional limitations:

- ➢ They are not for use in IDLH atmospheres.
- ➢ They are not for use in atmospheres containing less than 19.5 percent oxygen.
- ➢ Use only the hose lengths and pressure ranges specified in the operator's manual.
- ➢ Use only in atmospheres for which the air-purifying element is approved.

The approval label and operator's manual must be consulted for proper use of the respirator in the air-purifying mode. The restrictions can vary from manufacturer to manufacturer depending on the respirator design.

RESPIRATOR SELECTION

Proper selection of respirators must start with an assessment of the inhalation hazards present in the workplace. This

Figure 22–28. Combination air-purifying and air-line respirators provide protection in the event the air supply fails. (Courtesy 3M.)

assessment must include the following:

- ➢ The nature of the hazardous operation or process
- ➢ The type of respiratory hazard
- ➢ The location of the hazardous area in relation to the nearest respirable air source
- ➢ The time period that respirators must be worn
- ➢ The workers' activities

Respirators must then be selected for the situation after the physical characteristics and functional capabilities and limitations of the various types of respirators and their assigned protection factors (APFs) have been considered.

Selection Requirements

The OSHA Standard 29 *CFR* 1910.134 states that respirators shall be selected on the basis of the respiratory hazard(s) in the workplace and relevant workplace and user factors. A NIOSH-approved respirator must be selected. The workplace respiratory hazards must be identified and evaluated; this evaluation includes a reasonable estimate of worker exposures to respiratory hazard(s) and an identification of the contaminant's chemical state and physical form. If the respiratory hazard cannot be identified or the worker exposure estimated, the atmosphere must be considered IDLH. For certain respiratory hazards, specific instructions about respirator use are given in other OSHA regulations (for example, Asbestos, 1910.1001 and 1926.1101; Vinyl Chloride, 1910.1017; and substances regulated after promulgation of vinyl chloride). The trend is toward regulations that specify the conditions of respirator use for each substance.

The substance-specific OSHA standards list respiratory protection equipment for various concentrations of a substance. This is called the Respirator Selection Table (Table 22–G). To provide additional protection, an employer may select a respirator prescribed for concentrations higher than those found in the workplace. However, the employer may not use respirators that are not listed. These standards also call for a respiratory protection program as spelled out in 29 *CFR* 1910.134 of the OSHA regulations.

Table 22–G. ***Example of OSHA Respirator Selection Table: Respiratory Protection for Asbestos Fibers***

Airborne Concentration of Asbestos or Conditions of Use	***Required Respirator[a]***
Not in excess of l f/cc (10 x PEL), or otherwise as required independent of exposure pursuant to (h)(2)(iv).	Half-mask air-purifying respirator other than a disposable respirator, equipped with high efficiency filters[b]
Not in excess of 5 f/cc (50 x PEL)	Full facepiece air-purifying respirator equipped with high efficiency filters[b]
Not in excess of 10 f/cc (100 x PEL)	Any powered air-purifying respirator equipped with high efficiency filters[b] or any supplied air respirator operated in continuous flow mode
Not in excess of 100 f/cc (1,000 x PEL)	Full facepiece supplied air respirator operated in pressure demand mode
Greater than 100 f/cc (1,000 x PEL) or unknown concentration	Full facepiece supplied air respirator operated in pressure demand mode, equipped with an auxiliary positive pressure self-contained breathing apparatus

Note: a. Respirators assigned for high environmental concentrations may be used at lower concentrations, or when required respirator use is independent of concentration.

b. A high efficiency filter means a filter that is at least 99.97 percent efficient against mono-dispersed particles of 0.3 micrometers in diameter or larger. The equivalent 42 *CFR* 84 particulate filters are the N100, R100, and P100 filters.

(Reprinted from OSHA General Industry Standards, 29 *CFR* 1910.1001)

For the large number of chemicals for which OSHA does not have a substance-specific standard, the general selection requirements of 29 CFR 1910.134 must be followed. Consult the *ANSI Standard for Respiratory Protection, Z88.2-1992*, for additional guidance.

Respirator selection involves determining the hazard and following a selection logic to choose the correct type or class of respirator that offers adequate protection.

Hazard Determination

The steps for hazard determination are as follows:

1. If the potential for an oxygen-deficient atmosphere exists, measure the oxygen content.
2. Determine what contaminant(s) may be present in the workplace.
3. Determine whether there are Threshold Limit Values® (TLVs), Permissible Exposure Limits (PELs) or any other available exposure limits.
4. Determine if the IDLH concentration for the contaminant(s) is available.
5. Determine if there is a substance-specific health standard (e.g., lead, asbestos) for the contaminant(s). If so, there may be specific respirators required that will influence the selection process.
6. Determine the physical state of the contaminant. If the contaminant is an aerosol, determine whether the vapor pressure is significant at the maximum expected temperature of the work environment. In these situations it may be possible to have a significant portion of the contaminant concentration in the vapor phase, requiring respiratory protection for both the particle and vapor phase of the contaminant.
7. Measure or estimate the concentration of the contaminant(s).
8. Determine whether the contaminant(s) can be absorbed through the skin, cause skin sensitization, or be irritating to or corrosive to the eyes or skin. Respirators that provide skin or eye protection or air-supplied suits may be required in addition to providing protection from the inhalation hazard.
9. For gases or vapors, determine if a known odor, taste, or irritation threshold exists because these may provide a secondary indication for cartridge breakthrough.

SKIN ABSORPTION

Chemical absorption through skin can be a significant route of exposure. Depending on the chemical, this route of exposure may be more significant than absorption through the respiratory system. For example, assuming 100 percent skin absorption, two drops of aniline on the skin would be equivalent to an inhalation exposure at the ACGIH Threshold Limit Value (TLV®) for eight hours. To avoid this possibility, selection of protective clothing may be required. Respirators may provide limited skin protection by a full facepiece or hood that protects the face area from absorption of gaseous contaminants and splashes. For total skin protection, either chemical clothing that encapsulates the respirator and worker or supplied-air suits must be selected (Figure 22–29). Encapsulation suits are available from several suppliers.

Figure 22–29. Totally encapsulating suits can be selected to provide skin protection and accommodate the respirator. (Courtesy ILC Dover.)

Supplied-air suits are usually custom-made for the intended purpose of the user. Generally, they consist of a full body suit and an air line to supply air to the suit. For more information on supplied-air suits, consult *Respiratory Protection: A Manual and Guideline*.

WARNING PROPERTIES

In the past, warning properties such as odor, eye irritation, and respiratory irritation have been relied on almost completely for indicating when chemical cartridge breakthrough was starting. In fact, organic vapor chemical cartridges were approved by NIOSH only for those organic vapors with good warning properties. However, warning properties rely upon human senses that are not foolproof. The 1987 NIOSH Respirator Decision Logic described the typical wide variation of odor threshold in the general population (greater than two orders of magnitude). Other problems exist: shift in odor threshold due to extended low exposures, shifts due to simple colds and other illnesses, and failure to recognize odor because of distraction of the workplace competing for worker

attention. Given the variability among people with respect to detection of odors and differences in measuring odor thresholds, a better practice is to establish cartridge change-out schedules even for chemicals with "adequate warning properties." Because of this fact, when OSHA revised its respiratory protection standard, it prohibited the reliance on warning properties as the primary means for indicating when it was time to change the chemical cartridges. Instead, OSHA requires that a change schedule be established that identifies how long a chemical cartridge can be used in a particular workplace before being replaced. OSHA has indicated that if an effective change-out schedule can be established for chemicals with poor warning properties, chemical cartridges could also be used for these chemicals as well. ANSI Z88.2-1992 recognized this. NIOSH recently updated its policy to be consistent with OSHA by recognizing the use of change schedules and by recommending against reliance on warning properties. The warning properties in these cases, should be used as a secondary indicator for cartridge change-out.

Selection Steps

After information is collected in the hazard determination step, proper selection should be made as follows:

1. If there is an oxygen-deficient atmosphere (<19.5 percent O_2) consider the atmosphere IDLH (see next item and Figure 22–30).
2. If the potential contaminants present were unable to be identified, consider the atmosphere IDLH (see next item).
3. If no exposure limit or guideline is available and estimates of toxicity cannot be made, consider the atmosphere IDLH (see next item).
4. If the measured or estimated concentration of the contaminants exceed the IDLH levels, the atmosphere is IDLH (see next item).
5. Divide the measured or estimated concentration by the exposure limit or guideline to obtain a hazard ratio.
6. If a substance-specific standard exists for the contaminant, consider those guidelines/requirements.
7. If more than one chemical is present, potential additive and synergistic effects of exposure should be considered. If the ACGIH TLV® for mixtures is used, a result greater than unity (that is, one) is the hazard ratio. Select a respirator with an assigned protection factor (APF) greater than the value of the hazard ratio. If an air-purifying respirator is selected, go on to the next step.
8. If the contaminant is a particle, a respirator with a particulate filter must be selected. Determine the filter efficiency required. Use a class 100 (99.97% efficiency) filter if a specific regulation or regulatory policy requires it. If no such regulation or policy exists, a class 95 (95% efficiency) filter may be used. Next determine the filter series needed. If no oil is present, an N-, R-, or P-series filter may be selected for the respirator with the appropriate APF. If oil is present, either an R- or P-series filter must be selected. R-series filters must be changed after eight-hour use or after the respirator is loaded with 200 mg of aerosol. Where oil is suspected, but air samples have not been taken to determine its presence, an R- or P-series filter should be selected.
9. If the contaminant is a gas or vapor, a respirator with a cartridge effective against the contaminant and with an assigned protection factor greater than the hazard ratio must be selected. If there is no chemical cartridge that is effective against the contaminant, an atmosphere-supplying respirator with an appropriate APF must be selected.
10. For gases or vapors, determine if the effective chemical cartridge has an end-of-service-life indicator (ESLI) or if service life data exists to allow for a cartridge change-out schedule to be established.
11. If a respirator with either a chemical cartridge or canister is selected, establish a change schedule that results in replacing the cartridge or canister before significant

Figure 22–30. Pressure demand self-contained breathing apparatus are designed for use in oxygen deficient or immediately dangerous to life or health atmospheres as well as fire fighting. (Courtesy Scott Aviation Health and Safety Products.)

breakthrough (concentrations exceeding the exposure limit) occurs.

12. If the contaminant(s) is a particle and gas or vapor, such as with paint spray or pesticides, an air-purifying respirator with both an appropriate chemical cartridge and particulate filter or an atmosphere-supplying respirator must be selected. A change schedule for the cartridge or canister must be established.

IMMEDIATELY DANGEROUS TO LIFE OR HEALTH (IDLH)

Numerous definitions have been presented for IDLH atmospheres. OSHA defines *IDLH* as an atmosphere that poses an immediate threat to life, would cause irreversible adverse health effects, or would impair an individual's ability to escape from a dangerous atmosphere. The common theme in all the definitions is that IDLH atmospheres will affect the worker acutely as opposed to chronically. Thus, if the concentration is above the IDLH levels only highly reliable respiratory protective equipment is allowed. The only two devices that meet this requirement and provide escape provisions for the wearer are:

- ➢ A full-facepiece pressure-demand or other positive-pressure self-contained breathing apparatus (SCBA) certified for a minimum service life of 30 minutes.
- ➢ A combination type, full-facepiece pressure-demand airline respirator with auxiliary self-contained air supply.

The IDLH limits are conservative, so any approved respirator may be used up to this limit as long as the maximum use concentration for the device has not been exceeded (Figure 22–31). IDLH limits have not been established by OSHA. NIOSH has recommended IDLH values for many chemicals in the *NIOSH Pocket Guide to Chemical Hazards* for the purpose of respirator selection. Two factors have been considered when establishing IDLH concentrations:

- ➢ The worker must be able to escape without losing his or her life or suffering permanent health damage within 30 minutes. Thirty minutes is considered by NIOSH as the maximum permissible exposure time for escape.
- ➢ The worker must be able to escape without severe eye or respiratory irritation or other reactions that could inhibit escape.

A location is considered IDLH when an atmosphere is known or suspected to have chemical concentrations above the IDLH level or if a confined space contains less than the normal 20.9 percent oxygen, unless the reason for the reduced oxygen level is known. Otherwise according to OSHA, oxygen levels of less than 19.5 percent are IDLH unless the requirements for the OSHA exception discussed earlier can be met. When there is doubt about the oxygen content, the contaminants present or their airborne levels, the situation should be treated as IDLH. If an error in respirator selection is made, it should be on the side of safety. Thus in emergency situations, such as a spill, where the chemical or its airborne concentration are unknown, one of the above two respirators must be selected.

LOWER EXPLOSIVE LIMIT (LEL) AND FIRE FIGHTING

Concentrations in excess of the lower explosive limit (LEL) are considered to be IDLH. Generally, entry into atmospheres

Example of Maximum Use Concentration (MUC) Determination

Problem: What is the MUC for a half facepiece respirator with dust/mist filters for copper dust?
Solution: TLV for copper dust: 1 mg/m^3 APF for half facepiece respirator 10 MUC = TLV X APF = 1 mg/m^3 X 10 = 10 mg/m^3
Explanation: If air sampling indicates an ambient concentration greater than 10 mg/m^3, this respirator does not provide sufficient protection! Note that for half and full facepiece respirators, the filter or chemical cartridge type does not change the APF for the respirator.

Figure 22–31. Assigned protection factors (APFs) are used in the selection process to determine the maximum use concentration (MUC) for the respirator. It is determined by multiplying the TLV® by the APF (Table 22–H). The APFs should be used only when the employer has established a respiratory protection program meeting the requirements stated in this chapter and satisfactory fit testing has been performed.

Table 22–H. *NIOSH and ANSI Assigned Protection Factors*

Type of Respirator	*NIOSH Respirator Decision Logic*	*ANSI Z88.2-1992*
Air-Purifying		
Quarter-Mask	5	10
Half-Mask	10[A]	10
Full-Facepiece	50	100
Powered Air-Purifying		
Half-Facepiece	50	50
Full-Facepiece	50	1000
Loose-Fitting Facepiece	25	25
Hood or Helmet	25	1000
Air-line		
Half-Facepiece		
Demand	10	10
Continuous-Flow	50	50
Pressure-Demand	1000	50
Full-Facepiece		
Demand	50	100
Continuous-Flow	50	1000
Pressure-Demand	2000	1000
Loose-Fitting Facepiece	25	25
Hood or Helmet	25	1000
SCBA		
Demand[B]	50	100
Pressure Demand	10,000	10,000[C]

[A] Includes disposable particulate respirators if QNFT is used.

[B] Demand SCBA must not be used for emergency situations such as fire fighting.

[C] Although positive-pressure respirators are currently regarded as providing the highest level of respiratory protection, a limited number of recent simulated workplace studies concluded that all users may not achieve protection factors (APFs) of 10,000. Based on this limited data, a definitive APF could not be listed for positive-pressure SCBAs by ANSI Z88.2-1992. For emergency planning purposes where hazardous concentrations can be estimated, an APF of no higher than 10,000 should be used.

NOTE: Assigned protection factors (APFs) are not applicable for escape-only respirators. For combination respirators for example, air-line respirators equipped with an air-purifying filter, the mode of operation in use will dictate the APF to be applied.

exceeding the LEL is not recommended except for life saving rescues. For concentrations at or above the LEL, respirators must provide maximum protection. Such devices include pressure-demand self-contained breathing apparatus and combination positive-pressure air-line respirators with egress cylinders.

The ANSI standard Z88.5, *Practices for Respiratory Protection for the Fire Service*, 1981, defines fire fighting as immediately dangerous to life, so for fire fighting, the only device providing adequate protection is the pressure-demand self-contained breathing apparatus. In addition to being NIOSH-approved, the SCBA used for fire fighting (Figure 22–30) should comply with the most current edition of the National Fire Protection Association (NFPA) standard, NFPA 1981 (last published in 1997).

ASSIGNED PROTECTION FACTORS

Assigned protection factors (APFs) are a very important part of the selection process. The assigned protection factor is the expected workplace level of respiratory protection that would be provided by a properly functioning respirator or a class of respirators to properly fitted and trained users. Simply stated, APFs are a measure of the overall effectiveness of a respirator used in conjunction with a good respirator program. The APFs recommended by ANSI Z88.2-1992 (Table 22–H) are based on tests measuring the performance of respirators in the workplace or simulated workplace environments. These studies are sometimes referred to as workplace protection factor studies. In these studies measurements are taken simultaneously outside and inside the respirator as the worker does their normal job (Figure 22–32). The results of these studies indicate that an APF of 10 for both disposable and elastomeric half-facepiece respirators is appropriate. An APF of 10 means the respirator will reduce the concentration actually breathed in by 10 times compared with the actual airborne concentration.

Sometimes the APFs that OSHA uses in the substance-specific standards will be different as the OSHA standards do not keep up with the latest information. These recommended APFs should be used only when the employer has established an acceptable respiratory protection program meeting the requirements of 29 *CFR* 1910.134 and satisfactory fit testing of tight-fitting respirators has been performed.

Another set of APFs was established by NIOSH in 1987 (Table 22–H). The majority of these APFs are based on quantitative fit testing of respirators approved by the U.S. Bureau of Mines. A few are based on workplace protection factor studies. Because there are currently no APFs in the

Figure 22–32. Workplace studies simultaneously measuring air contaminants outside and inside the respirator are being used to establish assigned protection factors for the classes of respirators. (Courtesy 3M.)

OSHA respirator standard, OSHA stated that it expects employers to take the best available information into account in selecting respirators. When evaluating recommended APFs, one should consider the basis for the APFs, how old the data are, and the date of the recommendation. Research in this area is ongoing and current data should be used. Quantitative fit-test results should not be used for establishing APFs, as studies have shown these do not correlate to protection factors measured in the workplace.

CHANGE-OUT SCHEDULE

When a respirator with an end-of-service-life indicator is not available, the only method available for replacing cartridges or canisters before breakthrough is by a cartridge change-out schedule. The objective data used to set a change schedule must be documented in a written respiratory protection program. It is not necessary to develop a cartridge change schedule for gas and vapor contaminants regulated by OSHA's substance-specific standards, since cartridge change schedules are specified in each regulation. A change schedule is a predetermined interval of time after which a used cartridge is replaced with a new one. In order to determine an appropriate change schedule, the breakthrough time for the gas or vapor in question must be known or estimated. Breakthrough means that a stated concentration of the chemical can be detected (measured) on the downstream side of the cartridge. The amount of time required to reach breakthrough is sometimes referred to as the service life of the cartridge. An appropriate cartridge change schedule is one that is both convenient and assures that the concentration of the chemical downstream does not exceed the exposure limit.

The service life estimate is the fundamental piece of information to base a change schedule on. Several methods can be used to estimate breakthrough times (that is, service life). These vary in cost, complexity and precision. All methods require professional judgment to establish an appropriate change schedule and all require the same basic information. This information includes the specific respirator and cartridge to be used, airborne concentration of the contaminant(s), temperature and humidity in the workplace, the pattern of respirator use (for example, hours per shift, shifts per week), and the expected work rate. Each of these can affect cartridge service life. Service life can be estimated using general guidelines, determined by testing cartridges in the laboratory or in the field, or calculated using breakthrough equations.

A few general guidelines for estimating the service life of organic vapor chemical cartridges exist. Basically, high boiling point materials are collected more efficiently than low boiling point materials. Guidelines for estimating change-out for organic vapor cartridges are:

- ➢ If the organic vapor's boiling point is greater than 70 C, and its concentration is less than 200 ppm, the organic vapor cartridge should last eight hours at a normal work rate (assuming normal breathing rate)
- ➢ Service life is inversely proportional to flow rate
- ➢ If the concentration is reduced by a factor of ten, the service life will only increase by five

There are no general guidelines to follow for the other types of chemical cartridges.

Respirator manufacturers, private testing laboratories and research scientists have done laboratory testing with some chemicals. Many commercial labs are equipped to run tests for a fee. Laboratory testing involves measuring the actual breakthrough time for a specific cartridge when tested with a specific chemical. The cartridge is mounted in a test apparatus, and a known concentration of the chemical is drawn through it at a specific flow rate, temperature, and humidity. The time it takes to detect a stated concentration of the chemical on the downstream side of the cartridge is measured. Laboratory testing gives an actual measurement of breakthrough time for the test conditions. Because laboratory studies are usually conducted at high concentrations to save time, professional judgment or rules of thumb must be used to apply this information to workplace conditions. It is also possible to conduct a series of tests at different concentrations and humidity levels in order to develop a breakthrough curve to predict the performance of the cartridge at a wide range of conditions. Laboratory testing can be done with mixtures, but problems of generating and controlling a complex test atmosphere must be overcome. The cost for laboratory testing is rather high, approximately $2,000 for a single chemical.

Much of the breakthrough data published in the literature were collected using cartridges manufactured more than 20 years ago. Table 22–E lists examples of published breakthrough data for several chemicals. Generally this information is for single chemicals, but it is possible to test more than one chemical simultaneously at concentrations and relative humidity that mimic the work environment. When the testing conditions are not representative of the workplace, it is more difficult to extrapolate to the workplace. Because respirator and carbon technology have improved over the years, modern cartridges are likely to perform better than published data indicate.

Field testing determines breakthrough time in the workplace. Air from the workplace is drawn through the cartridge, and the downstream air is monitored to determine when breakthrough occurs. Pumps capable of drawing 20 to 60 liters per minute are required, which typically means that the pump must be in a fixed location. Consequently, the challenge to the cartridge may not accurately represent workers' actual exposures. Field testing overcomes many of the disadvantages of mathematical models and laboratory testing. Relative humidity and the presence of several vapors in the atmosphere are automatically incorporated into the breakthrough measurement. However, field testing has the disadvantage of being relatively equipment- and labor-intensive. In addition, since workplace concentrations of each vapor vary considerably, samples may need to be collected over several days.

Breakthrough equations or mathematical models have been developed to estimate breakthrough time for organic vapor cartridges and canisters. The calculation of breakthrough time depends on solvent variables, carbon variables, and ambient conditions. The models currently used for organic vapors are limited to liquids, limited by humidity, and restricted to single chemicals. Mathematical models provide estimates of service life based on the physical properties of the chemical and the carbon used in the cartridges. Many respirator manufacturers have developed these models for use with their respirators. Some provide service life estimates for inorganic chemicals. These models can usually be obtained from the respirator manufacturer's website. It is important to use the service life estimate model for the brand of chemical cartridge being used.

To verify that the change schedule is appropriate, an alternate field testing procedure can be used. It determines the remaining service life of cartridges after use in the workplace. This type of test is used to demonstrate that the gas or vapor has **not** broken through. It is easily accomplished by sampling behind the cartridge near the end of the use period. Any sampling method with sufficient sensitivity to detect the chemical of interest at a concentration below the exposure limit can be used to take the sample. Sampling behind the cartridge has been used for a limited number of materials and exposures. It is a simple method that allows breakthrough to be measured in the workplace at the actual contaminant concentration, environmental conditions, and work rate. It enables verification of service life predictions from mathematical models or change schedules based on limited information. This method is also suitable for atmospheres containing several vapors. Its primary disadvantage is its labor intensity, particularly if no service life estimate is available.

Setting an appropriate change schedule requires professional judgment to interpret information and apply appropriate safety factors. This is especially true when general guidelines, laboratory data, field data, or mathematical models are used. An acceptable margin of safety between a service life estimate and a change schedule is influenced by:

- Toxicity of the chemical
- Warning properties
- Quality of data and assumptions
  - Exposure estimate
  - Service life data
  - Work rate estimate
  - Workplace temperature and humidity

Chemical migration must be considered when the change schedule includes nonuse time periods. For organic vapors with a boiling point less than 65 C, it is recommended that the organic vapor cartridge never be used longer than one shift even if the estimated service life is greater than the shift duration and the cartridge is used for only a short time during the shift. For chemicals with boiling points greater than 65 C, nonuse or storage periods of a few days, like over a weekend, may be a concern. The reuse pattern must be carefully evaluated even for these less volatile chemicals. Chemicals with low volatility will give long service lives, but even in these situations, use should probably not extend beyond a week or two even if the service life estimate is longer. For workers that use their respirators intermittently and perhaps in different environments, such as a maintenance worker or inspector, the organic vapor cartridges should probably never be reused.

The user can conduct desorption studies, mimicking the work conditions of use and nonuse, to determine acceptable patterns of reuse. The ANSI Z88.2-1992 American National Standard for Respiratory Protection recommends that organic vapor cartridges be changed daily unless desorption studies support longer use.

HEALTH CARE SETTINGS

One of the more recent worksites seeing increased respirator usage is health care settings. Respiratory-protective devices are being used to reduce exposure to aerosolized drugs (such as pentamidine, ribavirin, antineoplastics) and bioaerosols (such as droplet nuclei containing *Mycobacterium tuberculosis* [TB]). This area presents many challenges including unknown safe levels of exposure for these agents or respirator efficacy for bioaerosols. Acceptable airborne levels have not been established for many pharmaceutical drugs or potentially infectious aerosols. NIOSH-approved or certified respirators have not been tested against bioaerosols such as TB.

This lack of information makes the respirator selection process difficult. Use of a properly selected respirator may reduce the risk due to exposure to these materials, but cannot guarantee protection. Respirators with high assigned protection factors should be expected to reduce risk to a lower level than respirators with lower assigned protection factors when used within a respirator program and worn properly and diligently by the worker. On the other hand, respirators with higher assigned protection factors are more complex, burdensome to the worker, and costly. The proper balance needs to be achieved. Disposable particulate respirators mentioned earlier have been used in health care settings because of their simplicity, cost, and efficiency, and also because of the ease of disposal if they become contaminated. Reuse of a respirator or its disposal must also be consistent with the operating procedures of the infection-control program of the health care facility.

Effective Protection Factor

Another variable that is often overlooked when selecting a respirator is worker acceptability. If the device is not acceptable to the worker it probably will not be worn. A respirator must be worn to be effective. Not wearing a respirator for short periods of time while it is needed can have a profound effect on overall protection that a respirator is capable of providing. If a respirator is not worn, the protection factor it provides is one, that is, the individual is exposed to the ambient contaminant concentration.

Table 22–I. ***Effect of Wear Time on Effective Protection Factor***

	Effective Protection Factor			
	Percent time worn			
Assigned Protection Factor	**80%**	**90%**	**95%**	**100%**
10 e.g., half face APR[1]	3.6	5.3	6.9	10
25 e.g., PAPR w/LFF[2]	4.3	7.4	11.4	25
50 e.g., PAPR w/ HF[3]	4.6	8.5	14.5	50
100 e.g., full face APR	4.8	9.2	16.8	100
1000 e.g., air-line, PD, FF[4]	4.98	9.9	19.6	1000
10,000 e.g., SCBA, PD[5]	4.99	9.99	19.9	10,000

[1] APR - Air-purifying respirator

[2] PAPR w/LFF - powered air-purifying respirator with loose fitting facepiece

[3] PAPR w/HF - powered air-purifying respirator with half facepiece

[4] Air-line, PD, FF - pressure demand air-line respirator with full facepiece

[5] SCBA, PD - pressure demand self-contained breathing apparatus

The effect of not wearing the a respirator can be calculated from the following equation.

$$\text{Effective Protection Factor} = \frac{\text{Work shift time, min}}{(1/\text{APF})(\text{wear time, min}) + (\text{Non-wear time, min})}$$

The exposure during wear time can be reduced by the APF or any assumed level of protection.

For example, if a person removes their respirator for one minute to talk during a task that takes one hour, the wear time is 98 percent. If the person uses a respirator with a APF of 1,000, the effective level of protection (effective protection factor) received is 56 including this one minute of non-wear time. In training it is important that people understand the effect of non-wear time on the level of performance that can be achieved. As non-wear time increases for any respirator, the protection level for all respirators approaches one. Where poor wear habits exist, the effective protection levels of an SCBA and a half mask may be identical (Table 22–I).

RESPIRATOR FIT TESTING

After close consideration of all the details pertaining to respirator selection, proper protection will not be provided if the respirator facepiece does not fit the wearer properly. One make and model of respirator should not be expected to fit the entire work force. Because of the great variety in face sizes and shapes encountered in male and female workers, most respirator manufacturers make their models of respirators available in more than one size or make several models of the same respirator type. In addition, the size and shape of each facepiece varies among the different manufacturers. In other words, the medium-size half facepiece of one manufacturer is not the same shape and size as the medium-size half facepiece from another manufacturer. For these reasons, it may be necessary to buy several commercially available respirators to conduct a good respirator fit testing program. The exact number of respirators to meet this requirement will vary. For a small number of respirator wearers (for example, four) one manufacturers' style and size may suffice. On the other hand, for a larger employer with hundreds of respirator wearers, several manufacturers' respirators in various sizes may be necessary.

All tight-fitting (half- and full-facepiece) respirators, whether negative or positive pressure, must be fit tested. This includes disposable respirators. This can be achieved by one of two fitting methods: qualitative or quantitative fit testing. In either case, test agents or chemicals are used to detect leaks in the respirator facepiece-to-face seal. Fit testing should be conducted on all tight-fitting respirator wearers at least once every 12 months. The fit test must be repeated when a worker has a new condition that may affect the fit, such as a significant change in weight (plus or minus 10 percent or more), significant scarring in the face seal area, dental changes, or reconstructive or cosmetic surgery.

The fit test conductor should be able to set up the test equipment, prepare any solutions, and maintain the test respirators. This individual should be familiar with the physical characteristics that may interfere with a face seal (such as beards) and should be able to recognize improper respirator donning and performance of the user seal checks. The test conductor must also be able to perform the fit test and recognize a good test from an improper fit test. In addition, for quantitative fit testing, the fit tester should be able to perform preventive maintenance on the test equipment, check the system for leaks, and calibrate the equipment.

Qualitative Fit Testing

A qualitative fit test relies on the wearer's subjective response. The test agent is a substance that typically can be detected by the wearer such as isoamyl acetate (banana oil), saccharin, Bitrex™, or irritant smoke. The respirator must be equipped to remove the test agent (Figures 22–33 and 22–34). For example, if using isoamyl acetate, which is an organic chemical that gives off a vapor, an organic-vapor chemical cartridge must be used. With a respirator in good repair, if the wearer smells isoamyl acetate, the respirator does not fit well. These tests are relatively fast, easily performed, and use inexpensive equipment. Because these tests are based on the respirator wearer's subjective response to a test chemical, it is important that the purpose and importance of this test be thoroughly explained to the worker.

Four qualitative tests are commonly used. Detailed protocols are available in the OSHA Respiratory Protection Standard that must be followed when conducting fit testing. These tests have been shown to identify poor fitting respirators by studies conducted in the laboratory. Three tests have had sufficient testing to be considered validated. An important point for validation is to be able to generate reliably low concentrations of the test agent to test the workers' ability to identify low levels of the test

Figure 22–33. The isoamyl acetate qualitative fit test protocol requires respirators to be equipped with cartridges capable of removing organic vapors and uses a test enclosure. (Courtesy Survivair.)

Figure 22–34. The saccharin qualitative fit test can be used with any particulate or gas/vapor respirator with any particulate filter to determine adequacy of fit. (Courtesy 3M.)

agent inside the respirator. The validated fit test methods have been designed to assess fit factors of 100 (≤ 1 percent face seal leakage). When qualitative fit tests are used to fit test negative pressure respirators, the respirators can be used only in atmospheres up to ten times the occupational exposure limit (OEL). This means that if a full-facepiece negative-pressure respirator is fit tested qualitatively, it can be used only up to ten times the OEL. To use the full-facepiece respirator in concentrations up to its APF, quantitative fit testing must be performed. These test protocols that have been validated are the isoamyl acetate vapor test and the saccharin and Bitrex™ mist test. These tests have further been shown to be effective through workplace protection factor studies. Where these protocols have been used for fit testing, the results show the workers received adequate protection as indicated by the in-facepiece sampling results.

Qualitative Fit-Test Protocols

The qualitative fit-test protocols consist of three steps: threshold screening, respirator selection, and fit testing. The threshold screening step is performed without wearing a respirator to determine if the subject can detect low levels of the test agent. This level would be similar to the amount inside the respirator if the facepiece-to-face seal had a small leak. During this test, the test subject also learns what to expect if the respirator is leaking.

The purpose of the respirator selection step is to find one that provides the most comfortable fit. Every make and model respirator has a different size and shape. If the respirator is correctly chosen and properly worn and fit as indicated by a fit test, it should provide adequate protection. The respirators used in this step must be equipped with the filter or cartridge appropriate for the test agent. This is necessary to minimize the effects of filter or cartridge penetration so that only face-piece-to-face seal is evaluated. Respirators fit tested using isoamyl acetate must be equipped with organic vapor cartridges or canisters. Any respirator with a particulate filter can be fit tested with saccharin and Bitrex mist. The saccharin and Bitrex solution aerosol protocols are the only fit-test protocols currently available that are validated and can be used with disposable particulate respirators (filtering facepiece respirators) not equipped with class 100 filters. Respirators must be equipped with class 100 filters to be tested with irritant smoke.

The fit test consists of the test subject's wearing the respirator while exposed to the test agent and performing facial movements (exercises) to test the facepiece-to-face seal. The qualitative fit-test protocols are in Appendix A of 29 *CFR* 1910.134 (see Addendum).

ISOAMYL ACETATE PROTOCOL

This protocol uses an organic vapor as the test agent, therefore respirators equipped with organic vapor cartridges or canisters must be used. This minimizes the effects of cartridge penetration so only the facepiece-to-face seal is evaluated.

SACCHARIN AND BITREX SOLUTION AEROSOL PROTOCOL

These protocols use a test agent in the form of a fine mist. Therefore, the respirator must be equipped with particulate filters so only face seal leakage is evaluated. Each respirator must be equipped with a particulate filter, that is, N-, R-, or P-95–100 particulate filter. NIOSH has previously recommended against the saccharin fit test because of its classification as a potential carcinogen. However, NIOSH recently re-examined the potential risk to workers that would be posed by saccharin used in fit testing. Finding that the risk to workers from use of saccharin in respirator fit testing is extremely small and may be zero, and in accordance with the new REL (Recommended Exposure Limit) policy, NIOSH

Figure 22–35. A probed respirator is used for quantitative fit testing to measure aerosol inside the facepiece. (Courtesy 3M.)

Figure 22–36. A quantitative fit-test adapter that can be placed on the respirator for fit testing and then removed when finished. (Courtesy 3M.)

recommends both saccharin and Bitrex for use in qualitative respirator fit testing, consistent with OSHA's respiratory protection standard (29 *CFR* 1910.134).

IRRITANT FUME PROTOCOL

This protocol uses a particle produced by condensation. This process produces very small particles. Therefore, the respirator must be equipped with a class 100 or HEPA filters so only face seal leakage is evaluated. It is important to note there is no threshold screening test as the threshold levels for irritant smoke have not been established. For this reason, respiratory protection experts do not consider the irritant fume protocol as a validated fit-test method. NIOSH reviewed the revised protocol for the irritant smoke test in OSHA's final respiratory protection standard and concluded that a risk exists for overexposure to hydrogen chloride during a facepiece fit test. To check the test subject's sensitivity, they are required to breathe irritant smoke both before and after a successful fit test. Generated concentrations to which test subjects are subjected are not measured in the test protocol. A concentration of 5 ppm is the accepted threshold level at which a response is evoked from most persons. A fit test is a failure when a test subject experiences an involuntary cough or irritation. Retesting requires repeating the sensitivity check. In each case, the responses of coughing and irritation are the adverse health effects for which hydrogen chloride's exposure limits are intended to protect against. Consequently, NIOSH does not recommend the use of irritant smoke as a fit testing agent. It is acceptable for OSHA compliance, however.

Quantitative Fit Testing

A quantitative fit test measures actual leakage of a test gas, vapor, or aerosol into the facepiece. Instrumentation is used

Figure 22–37. A portable corn oil quantitative fit-test system utilizes a test enclosure. (Courtesy Air Techniques Inc.)

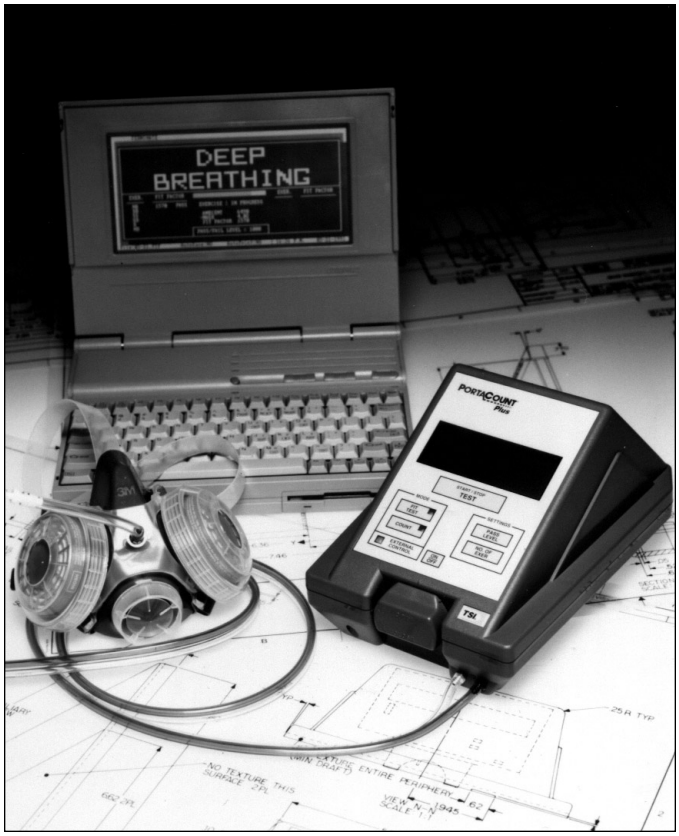

Figure 22–38. The ambient aerosol quantitative fit-test system does not use a test enclosure and must be used with respirators equipped with high efficiency filters. (Courtesy TSI.)

to sample and measure the test atmosphere and the air inside the respirator facepiece. With this information, a quantitative fit factor (or fit factor) is calculated. The fit factor is the ratio of the outside concentration to the concentration inside the respirator facepiece. The advantage of this type of testing is that it does not rely on a subjective response. The disadvantages are cost of instrumentation, need for highly trained personnel to conduct the test, and use of probed respirators (Figures 22–35, 22–36) to sample air from inside the respirator.

Commercially available quantitative fit testing equipment use sodium chloride and corn oil mist generating systems (Figure 22–37). These devices use test enclosures to contain the test agent. A newer system that measures the penetration of ambient aerosols into the facepiece is very portable (Figure 22–38). No test enclosure is required in this system. Fit testing with either of these systems must use respirators equipped with class 100 filters. Class 100 filters are used to minimize particle penetration through the filters and allow facepiece fit evaluations. Some of these instruments can be fitted with an adapter to allow quantitative fit testing of class 95 respirators.

A third method of quantitative fit testing does not involve aerosol measurement, but rather determines leakage by creating a negative pressure inside the facepiece and measuring the leakage rate of air. This technique is sometimes referred to as the controlled negative-pressure method (Figure 22–39). The respirator does not need a probe, but test adapter manifolds are placed on the respirator in place of filters or cartridges. Only respirators that can be adapted with the manifolds can be tested by this method. These manifolds are specific for the brand of respirator. The manifolds seal the respirator inlets so air cannot enter the respirator. One manifold contains a valve, which allows air to enter the respirator so the subject can breathe. The valve can be closed by squeezing a bulb hooked to this manifold. The second manifold contains ports so air can be pumped from the respirator, creating a negative pressure inside the facepiece.

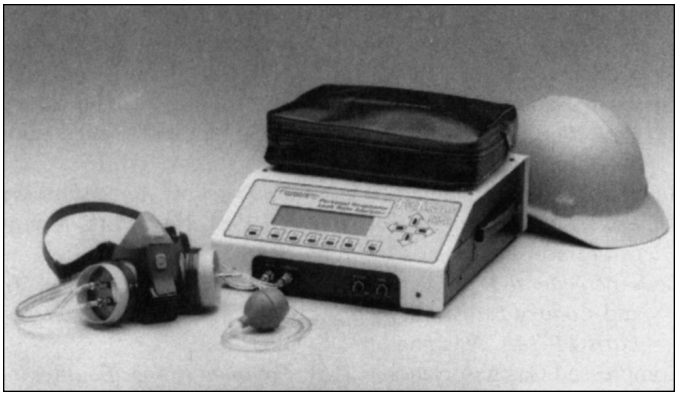

Figure 22–39. This quantitative fit-test equipment determines leakage by creating a negative pressure inside the facepiece similar to normal inspiratory pressures and measuring the leakage rate of air. (Courtesy Occupational Health Dynamics.)

To perform a test, the test subject puts on the properly equipped respirator, takes a deep breath, and holds it. The person conducting the test squeezes the bulb to "seal off" the respirator. The only way air can enter the respirator then is through face seal leaks. The instrument, which contains a pump to pull air out of the facepiece, is then started. Air is drawn out of the respirator until a predetermined "challenge pressure" is reached. This negative pressure created inside the facepiece causes air to leak into the facepiece from around the seal. The pump speed is then controlled to maintain the "challenge pressure." The amount of air pumped out of the respirator is equal to the air that leaks into the facepiece, thus the leak rate is measured. An equivalent fit factor is then calculated by the instrument comparing the airflow needed to maintain the negative pressure and the leak rate. A single measurement takes about 12 seconds. The OSHA protocol provides instructions on how to perform facial exercises while testing.

Quantitative Fit-Test Protocol

The OSHA standard provides protocols for three methods of quantitative fit testing: generated aerosol, ambient aerosol condensation nuclei counting, and controlled negative pressure quantitative fit testing protocols. These three commercially available methods are schematically represented in

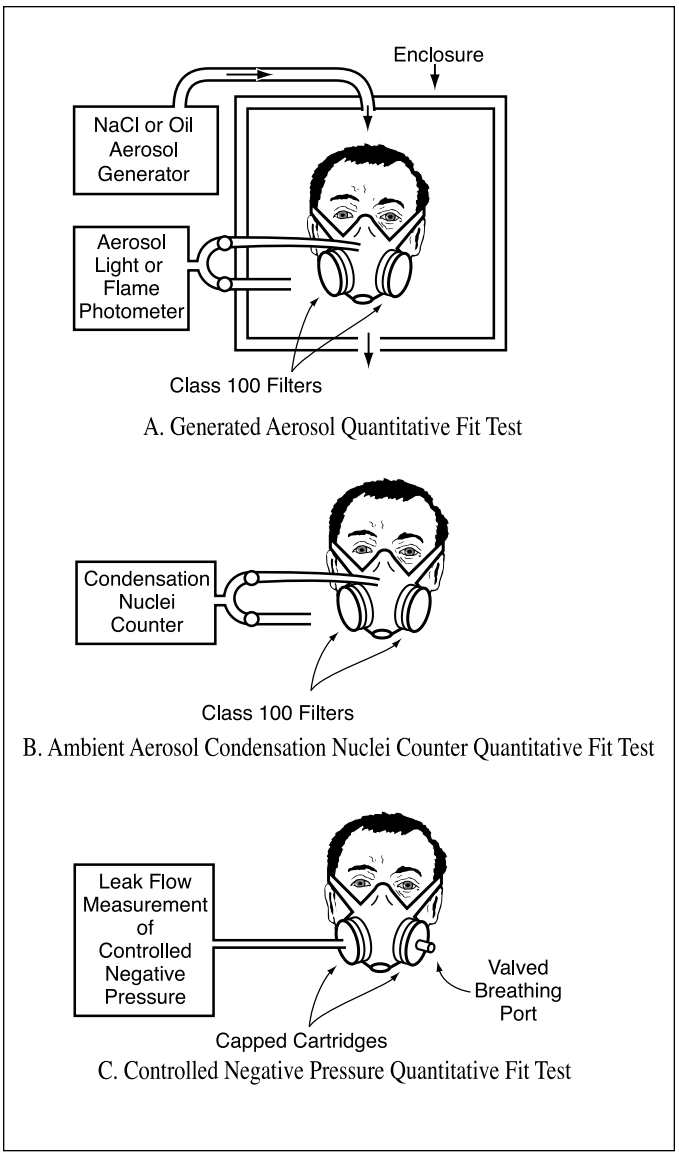

Figure 22–40. Schematic representation of commercially available quantitative fit tests. Adapted from Han DH, et al. *AIHA Journal* 58; 219–228, 1997.

Figure 22–40. This figure points out the major differences and similarities of the three quantitative fit-test methods.

If the TSI Portacount® Respirator Fit Tester is used, the worker should not be allowed to smoke within 30 minutes of the fit test. This can result in low fit factors since this instrument counts particles in the air. It is also important that all connections to tubing be tight. The respirator probe must not leak around the outside. These situations can result in low fit factors that do not reflect face seal leakage.

Positive-Pressure Respirators

Tight-fitting positive-pressure respirators must be either qualitatively or quantitatively fit tested in the negative-pressure mode. Qualitative fit testing of these respirators is accomplished by temporarily converting the respirator user's actual facepiece into a negative-pressure respirator with the appropriate filters, or by using an identical negative pressure air-purifying respirator facepiece with the same sealing surfaces as a surrogate for the atmosphere-supplying or powered air-purifying respirator facepiece. This can be done on tight-fitting powered air-purifying respirators by turning the blower off as long as the proper air-purifying element is on the respirator. Air-line respirators and SCBAs can be tested by obtaining the air-purifying model with the same facepiece used on the air-line respirator or SCBA. For some manufacturers, only filter or cartridge adapters need to be purchased that attach to the air-line respirator or SCBA facepiece. Combination air-line/air-purifying respirators can be fit tested in the negative-pressure mode by disconnecting from the air supply and placing the proper filter or cartridge in the holders. Quantitative fit testing of these respirators is done by modifying the converted or surrogate facepiece to allow sampling inside the facepiece in the breathing zone of the user, midway between the nose and mouth. This can be accomplished by installing a permanent sampling probe onto a surrogate facepiece (Figure 22–35), or by using a sampling adapter designed to temporarily provide a means of sampling air from inside the facepiece (Figure 22–36).

Table 22–J. ***Acceptable Fit-Testing Methods for Positive Pressure Tight-Fitting Respirators***

Respirator Type	*QLFT[A]*	*QNFT[B]*	*Minimum Fit Factor*	*APF[C]*
PAPR Half Facepiece	Yes	Yes	100	50
PAPR Full Facepiece	Yes	Yes	500	1000
Air Line Respirators, continuous flow or pressure demand mode				
➢Half Facepiece	Yes	Yes	100	50
➢Full Facepiece	Yes	Yes	500	1000
SCBA—Full Facepiece, Positive Pressure	Yes	Yes	500	10,000
SCBA/Air Line—Full Facepiece, Positive Pressure	Yes	Yes	500	10,000

[A]QLFT—Qualitative fit test

[B]QNFT—Quantitative fit test

[C] Assigned Protection Factor from *American National Standard for Respiratory Protection, ANSI Z88.2-1992.*

Any modifications to the respirator facepiece for fit testing must be completely removed, and the facepiece restored to the NIOSH-approved configuration, before that facepiece is used in the workplace.

The purpose for fit testing the facepiece of a positive-pressure respirator is to eliminate "gross" face seal leakage that might degrade protection **or** shorten service life for SCBA. Either qualitative or quantitative fit testing may be used for **all** positive pressure, tight-fitting atmosphere-supplying respirators and tight-fitting PAPRs. While these respirators are used as positive-pressure respirators in the workplace, they are fit tested in the negative-pressure mode. As a consequence, the minimum acceptable fit factor for a facepiece in the negative-pressure mode is lower than the APF, which is based on use in the positive-pressure mode. Positive-pressure respirators that pass the qualitative fit test or quantitative fit test may be used at the APFs of these respirators. Only the fitting capability of the facepiece is being evaluated, not the performance of the respirator. Successful completion of the qualitative fit test indicates the respirator fit is acceptable for the positive-pressure respirator. When quantitative fit testing is used, **all** respirators with a full-facepiece must meet or exceed a fit factor of 500, while half-mask respirators must meet or exceed 100. During qualitative fit testing a fit factor is not determined. If the qualitative fit test is passed, the fit is acceptable and the APF can be used. The assigned protection factors from Table 22–H can be issued after successful fit testing of the respirator. Table 22–J summarizes the fit testing requirements and APFs for tight-fitting positive-pressure respirators.

SUMMARY

The material presented in this chapter is intended for persons concerned with establishing and maintaining a respiratory protection program. It presents certain basic information for guidance purposes. However, it is not intended to be all-inclusive in content or scope.

Simplified interpretations of certain federal regulations pertaining to respiratory protection and monitoring were presented in this chapter. While these interpretations convey background information about the regulations, under no circumstances should they be used as the sole basis of a respiratory protection program. In all cases, the current federal regulations, as published in the *Federal Register* and later collected in the *Code of Federal Regulations*, should be carefully studied, and the rules and procedures in those regulations explicitly followed. Only they define the specific requirements that are in force. For additional information the reader should refer to the Bibliography.

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ADDENDUM: OSHA RESPIRATORY PROTECTION STANDARDS

29 *CFR* 1910.134 Respiratory Protection

1910.134 RESPIRATORY PROTECTION.

This section applies to General Industry (part 1910), Shipyards (part 1915), Marine Terminals (part 1917), Longshoring (part 1918), and Construction (part 1926).

(a) Permissible practice.

(1) In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors, the primary objective shall be to prevent atmospheric contamination. This shall be accomplished as far as feasible by accepted engineering control measures (for example, enclosure or confinement of the operation, general and local ventilation, and substitution of less toxic materials). When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators shall be used pursuant to this section.

(2) Respirators shall be provided by the employer when such equipment is necessary to protect the health of the employee. The employer shall provide the respirators which are applicable and suitable for the purpose intended. The employer shall be responsible for the establishment and maintenance of a respiratory protection program which shall include the requirements outlined in paragraph (c) of this section.

(b) Definitions.

The following definitions are important terms used in the respiratory protection standard in this section.

Air-purifying respirator means a respirator with an air-purifying filter, cartridge, or canister that removes specific air contaminants by passing ambient air through the air-purifying element.

Assigned protection factor (APF) [Reserved]

Atmosphere-supplying respirator means a respirator that supplies the respirator user with breathing air from a source independent of the ambient atmosphere, and includes supplied-air respirators (SARs) and self-contained breathing apparatus (SCBA) units.

Canister or cartridge means a container with a filter, sorbent, or catalyst, or combination of these items, which removes specific contaminants from the air passed through the container.

Demand respirator means an atmosphere-supplying respirator that admits breathing air to the facepiece only when a negative pressure is created inside the facepiece by inhalation.

Emergency situation means any occurrence such as, but not limited to, equipment failure, rupture of containers, or failure of control equipment that may or does result in an uncontrolled significant release of an airborne contaminant.

Employee exposure means exposure to a concentration of an airborne contaminant that would occur if the employee were not using respiratory protection.

End-of-service-life indicator (ESLI) means a system that warns the respirator user of the approach of the end of adequate respiratory protection, for example, that the sorbent is approaching saturation or is no longer effective.

Escape-only respirator means a respirator intended to be used only for emergency exit.

Filter or air purifying element means a component used in respirators to remove solid or liquid aerosols from the inspired air.

Filtering facepiece (dust mask) means a negative pressure particulate respirator with a filter as an integral part of the facepiece or with the entire facepiece composed of the filtering medium.

Fit factor means a quantitative estimate of the fit of a particular respirator to a specific individual, and typically estimates the ratio of the concentration of a substance in ambient air to its concentration inside the respirator when worn.

Fit test means the use of a protocol to qualitatively or quantitatively evaluate the fit of a respirator on an individual. [See also Qualitative fit test (QLFT) and Quantitative fit test (QNFT).]

Helmet means a rigid respiratory inlet covering that also provides head protection against impact and penetration.

High efficiency particulate air (HEPA) filter means a filter that is at least 99.97% efficient in removing monodisperse particles of 0.3 micrometers in diameter. The equivalent NIOSH 42 *CFR* 84 particulate filters are the N100, R100, and P100 filters.

Hood means a respiratory inlet covering that completely covers the head and neck and may also cover portions of the shoulders and torso.

Immediately dangerous to life or health (IDLH) means an atmosphere that poses an immediate threat to life, would cause irreversible adverse health effects, or would impair an individual's ability to escape from a dangerous atmosphere.

Interior structural firefighting means the physical activity of fire suppression, rescue or both, inside of buildings or enclosed structures which are involved in a fire situation beyond the incipient stage. (See 29 *CFR* 1910.155)

Loose-fitting facepiece means a respiratory inlet covering that is designed to form a partial seal with the face.

Maximum use concentration (MUC) [Reserved].

Negative pressure respirator (tight fitting) means a respirator in which the air pressure inside the facepiece is negative

during inhalation with respect to the ambient air pressure outside the respirator.

Oxygen deficient atmosphere means an atmosphere with an oxygen content below 19.5% by volume.

Physician or other licensed healthcare professional (PLHCP) means an individual whose legally permitted scope of practice (i.e., license, registration, or certification) allows him or her to independently provide, or be delegated the responsibility to provide, some or all of the health care services required by paragraph (e) of this section.

Positive pressure respirator means a respirator in which the pressure inside the respiratory inlet covering exceeds the ambient air pressure outside the respirator.

Powered air-purifying respirator (PAPR) means an air-purifying respirator that uses a blower to force the ambient air through air-purifying elements to the inlet covering.

Pressure demand respirator means a positive pressure atmosphere-supplying respirator that admits breathing air to the facepiece when the positive pressure is reduced inside the facepiece by inhalation.

Qualitative fit test (QLFT) means a pass/fail fit test to assess the adequacy of respirator fit that relies on the individual's response to the test agent.

Quantitative fit test (QNFT) means an assessment of the adequacy of respirator fit by numerically measuring the amount of leakage into the respirator.

Respiratory inlet covering means that portion of a respirator that forms the protective barrier between the user's respiratory tract and an air-purifying device or breathing air source, or both. It may be a facepiece, helmet, hood, suit, or a mouthpiece respirator with nose clamp.

Self-contained breathing apparatus (SCBA) means an atmosphere-supplying respirator for which the breathing air source is designed to be carried by the user.

Service life means the period of time that a respirator, filter or sorbent, or other respiratory equipment provides adequate protection to the wearer.

Supplied-air respirator (SAR) or airline respirator means an atmosphere-supplying respirator for which the source of breathing air is not designed to be carried by the user.

This section means this respiratory protection standard.

Tight-fitting facepiece means a respiratory inlet covering that forms a complete seal with the face.

User seal check means an action conducted by the respirator user to determine if the respirator is properly seated to the face.

(c) Respiratory protection program.

This paragraph requires the employer to develop and implement a written respiratory protection program with required worksite-specific procedures and elements for required respirator use. The program must be administered by a suitably trained program administrator. In addition, certain program elements may be required for voluntary use to prevent potential hazards associated with the use of the respirator. The Small Entity Compliance Guide contains criteria for the selection of a program administrator and a sample program that meets the requirements of this paragraph. Copies of the Small Entity Compliance Guide will be available on or about April 8, 1998 from the Occupational Safety and Health Administration's Office of Publications, Room N 3101, 200 Constitution Avenue, NW, Washington, DC, 20210 (202-219-4667).

(1) In any workplace where respirators are necessary to protect the health of the employee or whenever respirators are required by the employer, the employer shall establish and implement a written respiratory protection program with worksite-specific procedures. The program shall be updated as necessary to reflect those changes in workplace conditions that affect respirator use. The employer shall include in the program the following provisions of this section, as applicable:

(i) Procedures for selecting respirators for use in the workplace;

(ii) Medical evaluations of employees required to use respirators;

(iii) Fit testing procedures for tight-fitting respirators;

(iv) Procedures for proper use of respirators in routine and reasonably foreseeable emergency situations;

(v) Procedures and schedules for cleaning, disinfecting, storing, inspecting, repairing, discarding, and otherwise maintaining respirators;

(vi) Procedures to ensure adequate air quality, quantity, and flow of breathing air for atmosphere-supplying respirators;

(vii) Training of employees in the respiratory hazards to which they are potentially exposed during routine and emergency situations;

(viii) Training of employees in the proper use of respirators, including putting on and removing them, any limitations on their use, and their maintenance; and

(ix) Procedures for regularly evaluating the effectiveness of the program.

(2) Where respirator use is not required:

(i) An employer may provide respirators at the request of employees or permit employees to use their own respirators, if the employer determines that such respirator use will not in itself create a hazard. If the employer determines that any voluntary respirator use is permissible, the employer shall provide the respirator users with the information contained in Appendix D to this section ("Information for Employees Using Respirators When Not Required Under the Standard"); and

(ii) In addition, the employer must establish and implement those elements of a written respiratory protection program necessary to ensure that any employee using a respirator voluntarily is medically able to use that respirator, and that the respirator is

cleaned, stored, and maintained so that its use does not present a health hazard to the user.

Exception: Employers are not required to include in a written respiratory protection program those employees whose only use of respirators involves the voluntary use of filtering facepieces (dust masks).

(3) The employer shall designate a program administrator who is qualified by appropriate training or experience that is commensurate with the complexity of the program to administer or oversee the respiratory protection program and conduct the required evaluations of program effectiveness.

(4) The employer shall provide respirators, training, and medical evaluations at no cost to the employee.

(d) Selection of respirators.

This paragraph requires the employer to evaluate respiratory hazard(s) in the workplace, identify relevant workplace and user factors, and base respirator selection on these factors. The paragraph also specifies appropriately protective respirators for use in IDLH atmospheres, and limits the selection and use of air-purifying respirators.

(1) General requirements.

(i) The employer shall select and provide an appropriate respirator based on the respiratory hazard(s) to which the worker is exposed and workplace and user factors that affect respirator performance and reliability.

(ii) The employer shall select a NIOSH-certified respirator. The respirator shall be used in compliance with the conditions of its certification.

(iii) The employer shall identify and evaluate the respiratory hazard(s) in the workplace; this evaluation shall include a reasonable estimate of employee exposures to respiratory hazard(s) and an identification of the contaminant's chemical state and physical form. Where the employer cannot identify or reasonably estimate the employee exposure, the employer shall consider the atmosphere to be IDLH.

(iv) The employer shall select respirators from a sufficient number of respirator models and sizes so that the respirator is acceptable to, and correctly fits, the user.

(2) Respirators for IDLH atmospheres.

(i) The employer shall provide the following respirators for employee use in IDLH atmospheres:

(A) A full facepiece pressure demand SCBA certified by NIOSH for a minimum service life of thirty minutes, or

(B) A combination full facepiece pressure demand supplied-air respirator (SAR) with auxiliary self-contained air supply.

(ii) Respirators provided only for escape from IDLH atmospheres shall be NIOSH-certified for escape from the atmosphere in which they will be used.

(iii) All oxygen-deficient atmospheres shall be considered IDLH. Exception: If the employer demonstrates that, under all foreseeable conditions, the oxygen concentration can be maintained within the ranges specified in Table II of this section (i.e., for the altitudes set out in the table), then any atmosphere-supplying respirator may be used.

(3) Respirators for atmospheres that are not IDLH.

(i) The employer shall provide a respirator that is adequate to protect the health of the employee and ensure compliance with all other OSHA statutory and regulatory requirements, under routine and reasonably foreseeable emergency situations.

(A) Assigned Protection Factors (APFs) [Reserved]

(B) Maximum Use Concentration (MUC) [Reserved]

(ii) The respirator selected shall be appropriate for the chemical state and physical form of the contaminant.

(iii) For protection against gases and vapors, the employer shall provide:

(A) An atmosphere-supplying respirator, or

(B) An air-purifying respirator, provided that:

(1) The respirator is equipped with an end-of-service-life indicator (ESLI) certified by NIOSH for the contaminant; or

(2) If there is no ESLI appropriate for conditions in the employer's workplace, the employer implements a change schedule for canisters and cartridges that is based on objective information or data that will ensure that canisters and cartridges are changed before the end of their service life. The employer shall describe in the respirator program the information and data relied upon and the basis for the canister and cartridge change schedule and the basis for reliance on the data.

(iv) For protection against particulates, the employer shall provide:

(A) An atmosphere-supplying respirator; or

(B) An air-purifying respirator equipped with a filter certified by NIOSH under 30 *CFR* part 11 as a high efficiency particulate air (HEPA) filter, or an air-purifying respirator equipped with a filter certified for particulates by NIOSH under 42 CFR part 84; or

(C) For contaminants consisting primarily of particles with mass median aerodynamic diameters (MMAD) of at least 2 micrometers, an air-purifying respirator equipped with any filter certified for particulates by NIOSH.

TABLE I.-Assigned Protection Factors [Reserved]

TABLE II

Altitude (ft.)	Oxygen deficient Atmospheres (% 0_2) for which the employer may rely on atmosphere-supplying respirators
Less than 3001	16.0–19.5
3,001-4,000	16.4–19.5
4,001-5,000	17.1–19.5
5,001-6,000	17.8–19.5
6,001-7,000	18.5–19.5
7,001-8,000[1]	19.3–19.5

[1] Above 8,000 feet the exception does not apply. Oxygen-enriched breathing air must be supplied above 14,000 feet.

(e) Medical evaluation.

Using a respirator may place a physiological burden on employees that varies with the type of respirator worn, the job and workplace conditions in which the respirator is used, and the medical status of the employee. Accordingly, this paragraph specifies the minimum requirements for medical evaluation that employers must implement to determine the employee's ability to use a respirator.

(1) General. The employer shall provide a medical evaluation to determine the employee's ability to use a respirator, before the employee is fit tested or required to use the respirator in the workplace. The employer may discontinue an employee's medical evaluations when the employee is no longer required to use a respirator.

(2) Medical evaluation procedures.

(i) The employer shall identify a physician or other licensed health care professional (PLHCP) to perform medical evaluations using a medical questionnaire or an initial medical examination that obtains the same information as the medical questionnaire.

(ii) The medical evaluation shall obtain the information requested by the questionnaire in Sections 1 and 2, Part A of Appendix C of this section.

(3) Follow-up medical examination.

(i) The employer shall ensure that a follow-up medical examination is provided for an employee who gives a positive response to any question among questions 1 through 8 in Section 2, Part A of Appendix C or whose initial medical examination demonstrates the need for a follow-up medical examination.

(ii) The follow-up medical examination shall include any medical tests, consultations, or diagnostic procedures that the PLHCP deems necessary to make a final determination.

(4) Administration of the medical questionnaire and examinations.

(i) The medical questionnaire and examinations shall be administered confidentially during the employee's normal working hours or at a time and place convenient to the employee. The medical questionnaire shall be administered in a manner that ensures that the employee understands its content.

(ii) The employer shall provide the employee with an opportunity to discuss the questionnaire and examination results with the PLHCP.

(5) Supplemental information for the PLHCP.

(i) The following information must be provided to the PLHCP before the PLHCP makes a recommendation concerning an employee's ability to use a respirator:

(A) The type and weight of the respirator to be used by the employee;

(B) The duration and frequency of respirator use (including use for rescue and escape);

(C) The expected physical work effort;

(D) Additional protective clothing and equipment to be worn; and

(E) Temperature and humidity extremes that may be encountered.

(ii) Any supplemental information provided previously to the PLHCP regarding an employee need not be provided for a subsequent medical evaluation if the information and the PLHCP remain the same.

(iii) The employer shall provide the PLHCP with a copy of the written respiratory protection program and a copy of this section.

Note to Paragraph (e)(5)(iii): When the employer replaces a PLHCP, the employer must ensure that the new PLHCP obtains this information, either by providing the documents directly to the PLHCP or having the documents transferred from the former PLHCP to the new PLHCP. However, OSHA does not expect employers to have employees medically reevaluated solely because a new PLHCP has been selected.

(6) Medical determination. In determining the employee's ability to use a respirator, the employer shall:

(i) Obtain a written recommendation regarding the employee's ability to use the respirator from the PLHCP. The recommendation shall provide only the following information:

(A) Any limitations on respirator use related to the medical condition of the employee, or relating to the workplace conditions in which the respirator will be used, including whether or not the employee is medically able to use the respirator;

(B) The need, if any, for follow-up medical evaluations; and

(C) A statement that the PLHCP has provided the employee with a copy of the PLHCP's written recommendation.

(ii) If the respirator is a negative pressure respirator and the PLHCP finds a medical condition that may place the employee's health at increased risk if the respirator is used, the employer shall provide a PAPR if the PLHCP's medical evaluation finds that the employee can use such a respirator; if a subsequent medical evaluation finds that the employee is medically able to use a negative pressure respirator, then the employer is no longer required to provide a PAPR.

(7) Additional medical evaluations. At a minimum, the employer shall provide additional medical evaluations that comply with the requirements of this section if:

(i) An employee reports medical signs or symptoms that are related to ability to use a respirator;

(ii) A PLHCP, supervisor, or the respirator program administrator informs the employer that an employee needs to be reevaluated;

(iii) Information from the respiratory protection program, including observations made during fit testing and program evaluation, indicates a need for employee reevaluation; or

(iv) A change occurs in workplace conditions (e.g., physical work effort, protective clothing, temperature) that may result in a substantial increase in the physiological burden placed on an employee.

(f) Fit testing.

This paragraph requires that, before an employee may be required to use any respirator with a negative or positive pressure tight-fitting facepiece, the employee must be fit tested with the same make, model, style, and size of respirator that will be used. This paragraph specifies the kinds of fit tests allowed, the procedures for conducting them, and how the results of the fit tests must be used.

(1) The employer shall ensure that employees using a tight-fitting facepiece respirator pass an appropriate qualitative fit test (QLFT) or quantitative fit test (QNFT) as stated in this paragraph.

(2) The employer shall ensure that an employee using a tight-fitting facepiece respirator is fit tested prior to initial use of the respirator, whenever a different respirator facepiece (size, style, model or make) is used, and at least annually thereafter.

(3) The employer shall conduct an additional fit test whenever the employee reports, or the employer, PLHCP, supervisor, or program administrator makes visual observations of, changes in the employee's physical condition that could affect respirator fit. Such conditions include, but are not limited to, facial scarring, dental changes, cosmetic surgery, or an obvious change in body weight.

(4) If after passing a QLFT or QNFT, the employee subsequently notifies the employer, program administrator, supervisor, or PLHCP that the fit of the respirator is unacceptable, the employee shall be given a reasonable opportunity to select a different respirator facepiece and to be retested.

(5) The fit test shall be administered using an OSHA-accepted QLFT or QNFT protocol. The OSHA-accepted QLFT and QNFT protocols and procedures are contained in Appendix A of this section.

(6) QLFT may only be used to fit test negative pressure air-purifying respirators that must achieve a fit factor of 100 or less.

(7) If the fit factor, as determined through an OSHA-accepted QNFT protocol, is equal to or greater than 100 for tight-fitting half facepieces, or equal to or greater than 500 for tight-fitting full facepieces, the QNFT has been passed with that respirator.

(8) Fit testing of tight-fitting atmosphere-supplying respirators and tight-fitting powered air-purifying respirators shall be accomplished by performing quantitative or qualitative fit testing in the negative pressure mode, regardless of the mode of operation (negative or positive pressure) that is used for respiratory protection.

(i) Qualitative fit testing of these respirators shall be accomplished by temporarily converting the respirator user's actual facepiece into a negative pressure respirator with appropriate filters, or by using an identical negative pressure air-purifying respirator facepiece with the same sealing surfaces as a surrogate for the atmosphere-supplying or powered air-purifying respirator facepiece.

(ii) Quantitative fit testing of these respirators shall be accomplished by modifying the facepiece to allow sampling inside the facepiece in the breathing zone of the user, midway between the nose and mouth. This requirement shall be accomplished by installing a permanent sampling probe onto a surrogate facepiece, or by using a sampling adapter designed to temporarily provide a means of sampling air from inside the facepiece.

(iii) Any modifications to the respirator facepiece for fit testing shall be completely removed, and the facepiece restored to NIOSH-approved configuration, before that facepiece can be used in the workplace.

(g) Use of respirators.

This paragraph requires employers to establish and implement procedures for the proper use of respirators. These requirements include prohibiting conditions that may result in facepiece seal leakage, preventing employees from removing respirators in hazardous environments, taking actions to ensure continued effective respirator operation throughout the work shift, and establishing procedures for the use of respirators in IDLH atmospheres or in interior structural firefighting situations.

(1) Facepiece seal protection.
- **(i)** The employer shall not permit respirators with tight-fitting facepieces to be worn by employees who have:
  - **(A)** Facial hair that comes between the sealing surface of the facepiece and the face or that interferes with valve function; or
  - **(B)** Any condition that interferes with the face-to-facepiece seal or valve function.
- **(ii)** If an employee wears corrective glasses or goggles or other personal protective equipment, the employer shall ensure that such equipment is worn in a manner that does not interfere with the seal of the facepiece to the face of the user.
- **(iii)** For all tight-fitting respirators, the employer shall ensure that employees perform a user seal check each time they put on the respirator using the procedures in Appendix B–1 or procedures recommended by the respirator manufacturer that the employer demonstrates are as effective as those in Appendix B–1 of this section.

(2) Continuing respirator effectiveness.
- **(i)** Appropriate surveillance shall be maintained of work area conditions and degree of employee exposure or stress. When there is a change in work area conditions or degree of employee exposure or stress that may affect respirator effectiveness, the employer shall reevaluate the continued effectiveness of the respirator.
- **(ii)** The employer shall ensure that employees leave the respirator use area:
  - **(A)** To wash their faces and respirator facepieces as necessary to prevent eye or skin irritation associated with respirator use; or
  - **(B)** If they detect vapor or gas breakthrough, changes in breathing resistance, or leakage of the facepiece; or
  - **(C)** To replace the respirator or the filter, cartridge, or canister elements.
- **(iii)** If the employee detects vapor or gas breakthrough, changes in breathing resistance, or leakage of the facepiece, the employer must replace or repair the respirator before allowing the employee to return to the work area.

(3) Procedures for IDLH atmospheres. For all IDLH atmospheres, the employer shall ensure that:
- **(i)** One employee or, when needed, more than one employee is located outside the IDLH atmosphere;
- **(ii)** Visual, voice, or signal line communication is maintained between the employee(s) in the IDLH atmosphere and the employee(s) located outside the IDLH atmosphere;
- **(iii)** The employee(s) located outside the IDLH atmosphere are trained and equipped to provide effective emergency rescue;
- **(iv)** The employer or designee is notified before the employee(s) located outside the IDLH atmosphere enter the IDLH atmosphere to provide emergency rescue;
- **(v)** The employer or designee authorized to do so by the employer, once notified, provides necessary assistance appropriate to the situation;
- **(vi)** Employee(s) located outside the IDLH atmospheres are equipped with:
  - **(A)** Pressure demand or other positive pressure SCBAs, or a pressure demand or other positive pressure supplied-air respirator with auxiliary SCBA; and either
  - **(B)** Appropriate retrieval equipment for removing the employee(s) who enter(s) these hazardous atmospheres where retrieval equipment would contribute to the rescue of the employee(s) and would not increase the overall risk resulting from entry; or
  - **(C)** Equivalent means for rescue where retrieval equipment is not required under paragraph (g)(3)(vi)(B).

(4) Procedures for interior structural firefighting. In addition to the requirements set forth under paragraph (g)(3), in interior structural fires, the employer shall ensure that:
- **(i)** At least two employees enter the IDLH atmosphere and remain in visual or voice contact with one another at all times;
- **(ii)** At least two employees are located outside the IDLH atmosphere; and
- **(iii)** All employees engaged in interior structural firefighting use SCBAs.

Note 1 to paragraph (g): One of the two individuals located outside the IDLH atmosphere may be assigned to an additional role, such as incident commander in charge of the emergency or safety officer, so long as this individual is able to perform assistance or rescue activities without jeopardizing the safety or health of any firefighter working at the incident.

Note 2 to paragraph (g): Nothing in this section is meant to preclude firefighters from performing emergency rescue activities before an entire team has assembled.

(h) Maintenance and care of respirators.

This paragraph requires the employer to provide for the cleaning and disinfecting, storage, inspection, and repair of respirators used by employees.

(1) Cleaning and disinfecting. The employer shall provide each respirator user with a respirator that is clean, sanitary, and in good working order. The employer shall ensure that respirators are cleaned and disinfected using the procedures in Appendix B-2 of this section, or procedures recommended by the respirator manufacturer, provided that such procedures are of equivalent effectiveness. The respirators shall be cleaned and disinfected at the following intervals:

(i) Respirators issued for the exclusive use of an employee shall be cleaned and disinfected as often as necessary to be maintained in a sanitary condition;

(ii) Respirators issued to more than one employee shall be cleaned and disinfected before being worn by different individuals;

(iii) Respirators maintained for emergency use shall be cleaned and disinfected after each use; and

(iv) Respirators used in fit testing and training shall be cleaned and disinfected after each use.

(2) Storage. The employer shall ensure that respirators are stored as follows:

(i) All respirators shall be stored to protect them from damage, contamination, dust, sunlight, extreme temperatures, excessive moisture, and damaging chemicals, and they shall be packed or stored to prevent deformation of the facepiece and exhalation valve.

(ii) In addition to the requirements of paragraph (h)(2)(i) of this section, emergency respirators shall be:

(A) Kept accessible to the work area;

(B) Stored in compartments or in covers that are clearly marked as containing emergency respirators; and

(C) Stored in accordance with any applicable manufacturer instructions.

(3) Inspection.

(i) The employer shall ensure that respirators are inspected as follows:

(A) All respirators used in routine situations shall be inspected before each use and during cleaning;

(B) All respirators maintained for use in emergency situations shall be inspected at least monthly and in accordance with the manufacturer's recommendations, and shall be checked for proper function before and after each use; and

(C) Emergency escape-only respirators shall be inspected before being carried into the workplace for use.

(ii) The employer shall ensure that respirator inspections include the following:

(A) A check of respirator function, tightness of connections, and the condition of the various parts including, but not limited to, the facepiece, head straps, valves, connecting tube, and cartridges, canisters or filters; and

(B) A check of elastomeric parts for pliability and signs of deterioration.

(iii) In addition to the requirements of paragraphs (h)(3)(i) and (ii) of this section, self-contained breathing apparatus shall be inspected monthly. Air and oxygen cylinders shall be maintained in a fully charged state and shall be recharged when the pressure falls to 90% of the manufacturer's recommended pressure level. The employer shall determine that the regulator and warning devices function properly.

(iv) For respirators maintained for emergency use, the employer shall:

(A) Certify the respirator by documenting the date the inspection was performed, the name (or signature) of the person who made the inspection, the findings, required remedial action, and a serial number or other means of identifying the inspected respirator; and

(B) Provide this information on a tag or label that is attached to the storage compartment for the respirator, is kept with the respirator, or is included in inspection reports stored as paper or electronic files. This information shall be maintained until replaced following a subsequent certification.

(4) Repairs. The employer shall ensure that respirators that fail an inspection or are otherwise found to be defective are removed from service, and are discarded or repaired or adjusted in accordance with the following procedures:

(i) Repairs or adjustments to respirators are to be made only by persons appropriately trained to perform such operations and shall use only the respirator manufacturer's NIOSH-approved parts designed for the respirator;

(ii) Repairs shall be made according to the manufacturer's recommendations and specifications for the type and extent of repairs to be performed; and

(iii) Reducing and admission valves, regulators, and alarms shall be adjusted or repaired only by the manufacturer or a technician trained by the manufacturer.

(i) Breathing air quality and use.

This paragraph requires the employer to provide employees using atmosphere-supplying respirators (supplied-air and SCBA) with breathing gases of high purity.

(1) The employer shall ensure that compressed air, compressed oxygen, liquid air, and liquid oxygen used for respiration accords with the following specifications:

(i) Compressed and liquid oxygen shall meet the United States Pharmacopoeia requirements for medical or breathing oxygen; and

(ii) Compressed breathing air shall meet at least the requirements for Grade D breathing air described in ANSI/Compressed Gas Association Commodity Specification for Air, G-7.1-1989, to include:

(A) Oxygen content (v/v) of 19.5–23.5%;
(B) Hydrocarbon (condensed) content of 5 milligrams per cubic meter of air or less;
(C) Carbon monoxide (CO) content of 10 ppm or less;
(D) Carbon dioxide content of 1,000 ppm or less; and
(E) Lack of noticeable odor.

(2) The employer shall ensure that compressed oxygen is not used in atmosphere-supplying respirators that have previously used compressed air.

(3) The employer shall ensure that oxygen concentrations greater than 23.5% are used only in equipment designed for oxygen service or distribution.

(4) The employer shall ensure that cylinders used to supply breathing air to respirators meet the following requirements:
(i) Cylinders are tested and maintained as prescribed in the Shipping Container Specification Regulations of the Department of Transportation (49 *CFR* part 173 and part 178);
(ii) Cylinders of purchased breathing air have a certificate of analysis from the supplier that the breathing air meets the requirements for Grade D breathing air; and
(iii) The moisture content in the cylinder does not exceed a dew point of –50°F (–45.6°C) at 1 atmosphere pressure.

(5) The employer shall ensure that compressors used to supply breathing air to respirators are constructed and situated so as to:
(i) Prevent entry of contaminated air into the air-supply system;
(ii) Minimize moisture content so that the dew point at 1 atmosphere pressure is 10 degrees F (5.56°C) below the ambient temperature;
(iii) Have suitable in-line air-purifying sorbent beds and filters to further ensure breathing air quality. Sorbent beds and filters shall be maintained and replaced or refurbished periodically following the manufacturer's instructions.
(iv) Have a tag containing the most recent change date and the signature of the person authorized by the employer to perform the change. The tag shall be maintained at the compressor.

(6) For compressors that are not oil-lubricated, the employer shall ensure that carbon monoxide levels in the breathing air do not exceed 10 ppm.

(7) For oil-lubricated compressors, the employer shall use a high-temperature or carbon monoxide alarm, or both, to monitor carbon monoxide levels. If only high-temperature alarms are used, the air supply shall be monitored at intervals sufficient to prevent carbon monoxide in the breathing air from exceeding 10 ppm.

(8) The employer shall ensure that breathing air couplings are incompatible with outlets for nonrespirable worksite air or other gas systems. No asphyxiating substance shall be introduced into breathing air lines.

(9) The employer shall use breathing gas containers marked in accordance with the NIOSH respirator certification standard, 42 *CFR* part 84.

(j) Identification of filters, cartridges, and canisters.
The employer shall ensure that all filters, cartridges and canisters used in the workplace are labeled and color coded with the NIOSH approval label and that the label is not removed and remains legible.

(k) Training and information.
This paragraph requires the employer to provide effective training to employees who are required to use respirators. The training must be comprehensive, understandable, and recur annually, and more often if necessary. This paragraph also requires the employer to provide the basic information on respirators in Appendix D of this section to employees who wear respirators when not required by this section or by the employer to do so.

(1) The employer shall ensure that each employee can demonstrate knowledge of at least the following:
(i) Why the respirator is necessary and how improper fit, usage, or maintenance can compromise the protective effect of the respirator;
(ii) What the limitations and capabilities of the respirator are;
(iii) How to use the respirator effectively in emergency situations, including situations in which the respirator malfunctions;
(iv) How to inspect, put on and remove, use, and check the seals of the respirator;
(v) What the procedures are for maintenance and storage of the respirator;
(vi) How to recognize medical signs and symptoms that may limit or prevent the effective use of respirators; and
(vii) The general requirements of this section.

(2) The training shall be conducted in a manner that is understandable to the employee.

(3) The employer shall provide the training prior to requiring the employee to use a respirator in the workplace.

(4) An employer who is able to demonstrate that a new employee has received training within the last 12 months that addresses the elements specified in paragraph (k)(1)(i) through (vii) is not required to repeat such training provided that, as required by paragraph (k)(1), the employee can demonstrate knowledge of those element(s). Previous training not repeated initially by the employer must be provided no later than 12 months from the date of the previous training.

(5) Retraining shall be administered annually, and when the following situations occur:
- **(i)** Changes in the workplace or the type of respirator render previous training obsolete;
- **(ii)** Inadequacies in the employee's knowledge or use of the respirator indicate that the employee has not retained the requisite understanding or skill; or
- **(iii)** Any other situation arises in which retraining appears necessary to ensure safe respirator use.

(6) The basic advisory information on respirators, as presented in Appendix D of this section, shall be provided by the employer in any written or oral format, to employees who wear respirators when such use is not required by this section or by the employer.

(l) Program evaluation.

This section requires the employer to conduct evaluations of the workplace to ensure that the written respiratory protection program is being properly implemented, and to consult employees to ensure that they are using the respirators properly.

(1) The employer shall conduct evaluations of the workplace as necessary to ensure that the provisions of the current written program are being effectively implemented and that it continues to be effective.

(2) The employer shall regularly consult employees required to use respirators to assess the employees' views on program effectiveness and to identify any problems. Any problems that are identified during this assessment shall be corrected. Factors to be assessed include, but are not limited to:
- **(i)** Respirator fit (including the ability to use the respirator without interfering with effective workplace performance);
- **(ii)** Appropriate respirator selection for the hazards to which the employee is exposed;
- **(iii)** Proper respirator use under the workplace conditions the employee encounters; and
- **(iv)** Proper respirator maintenance.

(m) Recordkeeping.

This section requires the employer to establish and retain written information regarding medical evaluations, fit testing, and the respirator program. This information will facilitate employee involvement in the respirator program, assist the employer in auditing the adequacy of the program, and provide a record for compliance determinations by OSHA.

(1) Medical evaluation. Records of medical evaluations required by this section must be retained and made available in accordance with 29 *CFR* 1910.1020.

(2) Fit testing.
- **(i)** The employer shall establish a record of the qualitative and quantitative fit tests administered to an employee including:
  - **(A)** The name or identification of the employee tested;
  - **(B)** Type of fit test performed;
  - **(C)** Specific make, model, style, and size of respirator tested;
  - **(D)** Date of test; and
  - **(E)** The pass/fail results for QLFTs or the fit factor and strip chart recording or other recording of the test results for QNFTs.
- **(ii)** Fit test records shall be retained for respirator users until the next fit test is administered.

(3) A written copy of the current respirator program shall be retained by the employer.

(4) Written materials required to be retained under this paragraph shall be made available upon request to affected employees and to the Assistant Secretary or designee for examination and copying.

(n) Dates.

(1) Effective date. This section is effective April 8, 1998. The obligations imposed by this section commence on the effective date unless otherwise noted in this paragraph. Compliance with obligations that do not commence on the effective date shall occur no later than the applicable start-up date.

(2) Compliance dates. All obligations of this section commence on the effective date except as follows:
- **(i)** The determination that respirator use is required (paragraph (a)) shall be completed no later than September 8, 1998.
- **(ii)** Compliance with provisions of this section for all other provisions shall be completed no later than October 5, 1998.

(3) The provisions of 29 *CFR* 1910.134 and 29 *CFR* 1926.103, contained in the 29 *CFR* parts 1900 to 1910.99 and the 29 *CFR* part 1926 editions, revised as of July 1, 1997, are in effect and enforceable until October 5, 1998, or during any administrative or judicial stay of the provisions of this section.

(4) Existing Respiratory Protection Programs. If, in the 12 month period preceding April 8, 1998, the employer has conducted annual respirator training, fit testing, respirator program evaluation, or medical evaluations, the employer may use the results of those activities to comply with the corresponding provisions of this section, providing that these activities were conducted in a manner that meets the requirements of this section.

(o) Appendices.

(1) Compliance with Appendix A, Appendix B-1, Appendix B-2, and Appendix C of this section is mandatory.

(2) Appendix D of this section is non-mandatory and is not intended to create any additional obligations not otherwise imposed or to detract from any existing obligations.

APPENDIX A TO § 1910.134: FIT TESTING PROCEDURES (MANDATORY)

Part I. OSHA-Accepted Fit Test Protocols

A. FIT TESTING PROCEDURES—GENERAL REQUIREMENTS

The employer shall conduct fit testing using the following procedures. The requirements in this appendix apply to all OSHA-accepted fit test methods, both QLFT and QNFT.

1. The test subject shall be allowed to pick the most acceptable respirator from a sufficient number of respirator models and sizes so that the respirator is acceptable to, and correctly fits, the user.
2. Prior to the selection process, the test subject shall be shown how to put on a respirator, how it should be positioned on the face, how to set strap tension and how to determine an acceptable fit. A mirror shall be available to assist the subject in evaluating the fit and positioning of the respirator. This instruction may not constitute the subject's formal training on respirator use, because it is only a review.
3. The test subject shall be informed that he/she is being asked to select the respirator that provides the most acceptable fit. Each respirator represents a different size and shape, and if fitted and used properly, will provide adequate protection.
4. The test subject shall be instructed to hold each chosen facepiece up to the face and eliminate those that obviously do not give an acceptable fit.
5. The more acceptable facepieces are noted in case the one selected proves unacceptable; the most comfortable mask is donned and worn at least five minutes to assess comfort. Assistance in assessing comfort can be given by discussing the points in the following item A.6. If the test subject is not familiar with using a particular respirator, the test subject shall be directed to don the mask several times and to adjust the straps each time to become adept at setting proper tension on the straps.
6. Assessment of comfort shall include a review of the following points with the test subject and allowing the test subject adequate time to determine the comfort of the respirator:
   (a) Position of the mask on the nose
   (b) Room for eye protection
   (c) Room to talk
   (d) Position of mask on face and cheeks
7. The following criteria shall be used to help determine the adequacy of the respirator fit:
   (a) Chin properly placed;
   (b) Adequate strap tension, not overly tightened;
   (c) Fit across nose bridge;
   (d) Respirator of proper size to span distance from nose to chin;
   (e) Tendency of respirator to slip;
   (f) Self-observation in mirror to evaluate fit and respirator position.
8. The test subject shall conduct a user seal check, either the negative and positive pressure seal checks described in Appendix B–1 of this section or those recommended by the respirator manufacturer which provide equivalent protection to the procedures in Appendix B-1. Before conducting the negative and positive pressure checks, the subject shall be told to seat the mask on the face by moving the head from side-to-side and up and down slowly while taking in a few slow deep breaths. Another facepiece shall be selected and retested if the test subject fails the user seal check tests.
9. The test shall not be conducted if there is any hair growth between the skin and the facepiece sealing surface, such as stubble beard growth, beard, mustache or sideburns which cross the respirator sealing surface. Any type of apparel which interferes with a satisfactory fit shall be altered or removed.
10. If a test subject exhibits difficulty in breathing during the tests, she or he shall be referred to a physician or other licensed health care professional, as appropriate, to determine whether the test subject can wear a respirator while performing her or his duties.
11. If the employee finds the fit of the respirator unacceptable, the test subject shall be given the opportunity to select a different respirator and to be retested.
12. **Exercise regimen.** Prior to the commencement of the fit test, the test subject shall be given a description of the fit test and the test subject's responsibilities during the test procedure. The description of the process shall include a description of the test exercises that the subject will be performing. The respirator to be tested shall be worn for at least 5 minutes before the start of the fit test.
13. The fit test shall be performed while the test subject is wearing any applicable safety equipment that may be worn during actual respirator use which could interfere with respirator fit.
14. **Test Exercises.**
   (a) The following test exercises are to be performed for all fit testing methods prescribed in this appendix, except for the CNP method. A separate fit testing exercise regimen is contained in the CNP protocol. The test subject shall perform exercises, in the test environment, in the following manner:
      (1) Normal breathing. In a normal standing position, without talking, the subject shall breathe normally.
      (2) Deep breathing. In a normal standing position, the subject shall breathe slowly and deeply, taking caution so as not to hyperventilate.
      (3) Turning head side to side. Standing in place, the subject shall slowly turn his/her head from side to side between the extreme positions on each side. The head shall be held at each extreme momentarily so the subject can inhale at each side.
      (4) Moving head up and down. Standing in place, the subject shall slowly move his/her head up

and down. The subject shall be instructed to inhale in the up position (i.e., when looking toward the ceiling).

(5) Talking. The subject shall talk out loud slowly and loud enough so as to be heard clearly by the test conductor. The subject can read from a prepared text such as the Rainbow Passage, count backward from 100, or recite a memorized poem or song.

Rainbow Passage

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond reach, his friends say he is looking for the pot of gold at the end of the rainbow.

(6) Grimace. The test subject shall grimace by smiling or frowning. (This applies only to QNFT testing; it is not performed for QLFT)

(7) Bending over. The test subject shall bend at the waist as if he/she were to touch his/her toes. Jogging in place shall be substituted for this exercise in those test environments such as shroud type QNFT or QLFT units that do not permit bending over at the waist.

(8) Normal breathing. Same as exercise (1).

(b) Each test exercise shall be performed for one minute except for the grimace exercise which shall be performed for 15 seconds. The test subject shall be questioned by the test conductor regarding the comfort of the respirator upon completion of the protocol. If it has become unacceptable, another model of respirator shall be tried. The respirator shall not be adjusted once the fit test exercises begin. Any adjustment voids the test, and the fit test must be repeated.

B. Qualitative Fit Test (QLFT) Protocols

1. General

(a) The employer shall ensure that persons administering QLFT are able to prepare test solutions, calibrate equipment and perform tests properly, recognize invalid tests, and ensure that test equipment is in proper working order.

(b) The employer shall ensure that QLFT equipment is kept clean and well maintained so as to operate within the parameters for which it was designed.

2. Isoamyl Acetate Protocol

Note: This protocol is not appropriate to use for the fit testing of particulate respirators. If used to fit test particulate respirators, the respirator must be equipped with an organic vapor filter.

(a) Odor Threshold Screening

Odor threshold screening, performed without wearing a respirator, is intended to determine if the individual tested can detect the odor of isoamyl acetate at low levels.

(1) Three 1 liter glass jars with metal lids are required.

(2) Odor-free water (e.g., distilled or spring water) at approximately 25 C (77 F) shall be used for the solutions.

(3) The isoamyl acetate (IAA) (also known at isopentyl acetate) stock solution is prepared by adding 1 ml of pure IAA to 800 ml of odor-free water in a 1 liter jar, closing the lid and shaking for 30 seconds. A new solution shall be prepared at least weekly.

(4) The screening test shall be conducted in a room separate from the room used for actual fit testing. The two rooms shall be well-ventilated to prevent the odor of IAA from becoming evident in the general room air where testing takes place.

(5) The odor test solution is prepared in a second jar by placing 0.4 ml of the stock solution into 500 ml of odor-free water using a clean dropper or pipette. The solution shall be shaken for 30 seconds and allowed to stand for two to three minutes so that the IAA concentration above the liquid may reach equilibrium. This solution shall be used for only one day.

(6) A test blank shall be prepared in a third jar by adding 500 cc of odor-free water.

(7) The odor test and test blank jar lids shall be labeled (e.g., 1 and 2) for jar identification. Labels shall be placed on the lids so that they can be peeled off periodically and switched to maintain the integrity of the test.

(8) The following instruction shall be typed on a card and placed on the table in front of the two test jars (i.e., 1 and 2): "The purpose of this test is to determine if you can smell banana oil at a low concentration. The two bottles in front of you contain water. One of these bottles also contains a small amount of banana oil. Be sure the covers are on tight, then shake each bottle for two seconds. Unscrew the lid of each bottle, one at a time, and sniff at the mouth of the bottle. Indicate to the test conductor which bottle contains banana oil."

(9) The mixtures used in the IAA odor detection test shall be prepared in an area separate from where the test is performed, in order to prevent olfactory fatigue in the subject.

(10) If the test subject is unable to correctly identify the jar containing the odor test solution, the IAA qualitative fit test shall not be performed.

(11) If the test subject correctly identifies the jar containing the odor test solution, the test subject may proceed to respirator selection and fit testing.

(b) Isoamyl Acetate Fit Test

(1) The fit test chamber shall be a clear 55-gallon drum liner suspended inverted over a 2-foot diameter frame so that the top of the chamber is about 6 inches above the test subject's head. If no drum liner is available, a similar chamber shall be constructed using plastic sheeting. The inside top center of the chamber shall have a small hook attached.

(2) Each respirator used for the fitting and fit testing shall be equipped with organic vapor cartridges or offer protection against organic vapors.

(3) After selecting, donning, and properly adjusting a respirator, the test subject shall wear it to the fit testing room. This room shall be separate from the room used for odor threshold screening and respirator selection, and shall be well-ventilated, as by an exhaust fan or lab hood, to prevent general room contamination.

(4) A copy of the test exercises and any prepared text from which the subject is to read shall be taped to the inside of the test chamber.

(5) Upon entering the test chamber, the test subject shall be given a 6-inch by 5-inch piece of paper towel, or other porous, absorbent, single-ply material, folded in half and wetted with 0.75 ml of pure IAA. The test subject shall hang the wet towel on the hook at the top of the chamber. An IAA test swab or ampule may be substituted for the IAA wetted paper towel provided it has been demonstrated that the alternative IAA source will generate an IAA test atmosphere with a concentration equivalent to that generated by the paper towel method.

(6) Allow two minutes for the IAA test concentration to stabilize before starting the fit test exercises. This would be an appropriate time to talk with the test subject; to explain the fit test, the importance of his/ her cooperation, and the purpose for the test exercises; or to demonstrate some of the exercises.

(7) If at any time during the test, the subject detects the banana-like odor of IAA, the test is failed. The subject shall quickly exit from the test chamber and leave the test area to avoid olfactory fatigue.

(8) If the test is failed, the subject shall return to the selection room and remove the respirator. The test subject shall repeat the odor sensitivity test, select and put on another respirator, return to the test area and again begin the fit test procedure described in (b) (1) through (7) above. The process continues until a respirator that fits well has been found. Should the odor sensitivity test be failed, the subject shall wait at least 5 minutes before retesting. Odor sensitivity will usually have returned by this time.

(9) If the subject passes the test, the efficiency of the test procedure shall be demonstrated by having the subject break the respirator face seal and take a breath before exiting the chamber.

(10) When the test subject leaves the chamber, the subject shall remove the saturated towel and return it to the person conducting the test, so that there is no significant IAA concentration buildup in the chamber during subsequent tests. The used towels shall be kept in a self-sealing plastic bag to keep the test area from being contaminated.

3. Saccharin Solution Aerosol Protocol

The entire screening and testing procedure shall be explained to the test subject prior to the conduct of the screening test.

(a) Taste threshold screening.

The saccharin taste threshold screening, performed without wearing a respirator, is intended to determine whether the individual being tested can detect the taste of saccharin.

(1) During threshold screening as well as during fit testing, subjects shall wear an enclosure about the head and shoulders that is approximately 12 inches in diameter by 14 inches tall with at least the front portion clear and that allows free movements of the head when a respirator is worn. An enclosure substantially similar to the 3M hood assembly, parts # FT 14 and # FT 15 combined, is adequate.

(2) The test enclosure shall have a 3/4-inch (1.9 cm) hole in front of the test subject's

nose and mouth area to accommodate the nebulizer nozzle.

(3) The test subject shall don the test enclosure. Throughout the threshold screening test, the test subject shall breathe through his/her slightly open mouth with tongue extended. The subject is instructed to report when he/she detects a sweet taste.

(4) Using a DeVilbiss Model 40 Inhalation Medication Nebulizer or equivalent, the test conductor shall spray the threshold check solution into the enclosure. The nozzle is directed away from the nose and mouth of the person. This nebulizer shall be clearly marked to distinguish it from the fit test solution nebulizer.

(5) The threshold check solution is prepared by dissolving 0.83 gram of sodium saccharin USP in 100 ml of warm water. It can be prepared by putting 1 ml of the fit test solution (see (b)(5) below) in 100 ml of distilled water.

(6) To produce the aerosol, the nebulizer bulb is firmly squeezed so that it collapses completely, then released and allowed to fully expand.

(7) Ten squeezes are repeated rapidly and then the test subject is asked whether the saccharin can be tasted. If the test subject reports tasting the sweet taste during the ten squeezes, the screening test is completed. The taste threshold is noted as ten regardless of the number of squeezes actually completed.

(8) If the first response is negative, ten more squeezes are repeated rapidly and the test subject is again asked whether the saccharin is tasted. If the test subject reports tasting the sweet taste during the second ten squeezes, the screening test is completed. The taste threshold is noted as twenty regardless of the number of squeezes actually completed.

(9) If the second response is negative, ten more squeezes are repeated rapidly and the test subject is again asked whether the saccharin is tasted. If the test subject reports tasting the sweet taste during the third set of ten squeezes, the screening test is completed. The taste threshold is noted as thirty regardless of the number of squeezes actually completed.

(10) The test conductor will take note of the number of squeezes required to solicit a taste response.

(11) If the saccharin is not tasted after 30 squeezes (step 10), the test subject is unable to taste saccharin and may not perform the saccharin fit test.

Note to paragraph 3. (a): If the test subject eats or drinks something sweet before the screening test, he/she may be unable to taste the weak saccharin solution.

(12) If a taste response is elicited, the test subject shall be asked to take note of the taste for reference in the fit test.

(13) Correct use of the nebulizer means that approximately 1 ml of liquid is used at a time in the nebulizer body.

(14) The nebulizer shall be thoroughly rinsed in water, shaken dry, and refilled at least each morning and afternoon or at least every four hours.

(b) Saccharin solution aerosol fit test procedure.

(1) The test subject may not eat, drink (except plain water), smoke, or chew gum for 15 minutes before the test.

(2) The fit test uses the same enclosure described in 3. (a) above.

(3) The test subject shall don the enclosure while wearing the respirator selected in section I. A. of this appendix. The respirator shall be properly adjusted and equipped with a particulate filter(s).

(4) A second DeVilbiss Model 40 Inhalation Medication Nebulizer or equivalent is used to spray the fit test solution into the enclosure. This nebulizer shall be clearly marked to distinguish it from the screening test solution nebulizer.

(5) The fit test solution is prepared by adding 83 grams of sodium saccharin to 100 ml of warm water.

(6) As before, the test subject shall breathe through the slightly open mouth with tongue extended, and report if he/she tastes the sweet taste of saccharin.

(7) The nebulizer is inserted into the hole in the front of the enclosure and an initial concentration of saccharin fit test solution is sprayed into the enclosure using the same number of squeezes (either 10, 20 or 30 squeezes) based on the number of squeezes required to elicit a taste response as noted during the screening test. A minimum of 10 squeezes is required.

(8) After generating the aerosol, the test subject shall be instructed to perform the exercises in section I. A. 14. of this appendix.

(9) Every 30 seconds the aerosol concentration shall be replenished using one half the original number of squeezes used initially (e.g., 5, 10 or 15).

(10) The test subject shall indicate to the test conductor if at any time during the fit test the taste of saccharin is detected. If the test subject does not report tasting the saccharin, the test is passed.

(11) If the taste of saccharin is detected, the fit is deemed unsatisfactory and the test is failed. A different respirator shall be tried and the entire test procedure is repeated (taste threshold screening and fit testing).

(12) Since the nebulizer has a tendency to clog during use, the test operator must make periodic checks of the nebulizer to ensure that it is not clogged. If clogging is found at the end of the test session, the test is invalid.

4. Bitrex TM (Denatonium Benzoate) Solution Aerosol Qualitative Fit Test Protocol

The Bitrex TM (Denatonium benzoate) solution aerosol QLFT protocol uses the published saccharin test protocol because that protocol is widely accepted. Bitrex is routinely used as a taste aversion agent in household liquids which children should not be drinking and is endorsed by the American Medical Association, the National Safety Council, and the American Association of Poison Control Centers. The entire screening and testing procedure shall be explained to the test subject prior to the conduct of the screening test.

(a) Taste Threshold Screening.

The Bitrex taste threshold screening, performed without wearing a respirator, is intended to determine whether the individual being tested can detect the taste of Bitrex.

(1) During threshold screening as well as during fit testing, subjects shall wear an enclosure about the head and shoulders that is approximately 12 inches (30.5 cm) in diameter by 14 inches (35.6 cm) tall. The front portion of the enclosure shall be clear from the respirator and allow free movement of the head when a respirator is worn. An enclosure substantially similar to the 3M hood assembly, parts # FT 14 and # FT 15 combined, is adequate.

(2) The test enclosure shall have a 3/4 inch (1.9 cm) hole in front of the test subject's nose and mouth area to accommodate the nebulizer nozzle.

(3) The test subject shall don the test enclosure. Throughout the threshold screening test, the test subject shall breathe through his or her slightly open mouth with tongue extended. The subject is instructed to report when he/she detects a bitter taste.

(4) Using a DeVilbiss Model 40 Inhalation Medication Nebulizer or equivalent, the test conductor shall spray the Threshold Check Solution into the enclosure. This Nebulizer shall be clearly marked to distinguish it from the fit test solution nebulizer.

(5) The Threshold Check Solution is prepared by adding 13.5 milligrams of Bitrex to 100 ml of 5% salt (NaCl) solution in distilled water.

(6) To produce the aerosol, the nebulizer bulb is firmly squeezed so that the bulb collapses completely, and is then released and allowed to fully expand.

(7) An initial ten squeezes are repeated rapidly and then the test subject is asked whether the Bitrex can be tasted. If the test subject reports tasting the bitter taste during the ten squeezes, the screening test is completed. The taste threshold is noted as ten regardless of the number of squeezes actually completed.

(8) If the first response is negative, ten more squeezes are repeated rapidly and the test subject is again asked whether the Bitrex is tasted. If the test subject reports tasting the bitter taste during the second ten squeezes, the screening test is completed. The taste threshold is noted as twenty regardless of the number of squeezes actually completed.

(9) If the second response is negative, ten more squeezes are repeated rapidly and the test subject is again asked whether the Bitrex is tasted. If the test subject reports tasting the bitter taste during the third set of ten squeezes, the screening test is completed. The taste threshold is noted as thirty regardless of the number of squeezes actually completed.

(10) The test conductor will take note of the number of squeezes required to solicit a taste response.

(11) If the Bitrex is not tasted after 30 squeezes (step 10), the test subject is unable to taste Bitrex and may not perform the Bitrex fit test.

(12) If a taste response is elicited, the test subject shall be asked to take note of the taste for reference in the fit test.

(13) Correct use of the nebulizer means that approximately 1 ml of liquid is used at a time in the nebulizer body.

(14) The nebulizer shall be thoroughly rinsed in water, shaken to dry, and refilled at least each morning and afternoon or at least every four hours.

(b) Bitrex Solution Aerosol Fit Test Procedure.

(1) The test subject may not eat, drink (except plain water), smoke, or chew gum for 15 minutes before the test.

(2) The fit test uses the same enclosure as that described in 4. (a) above.

(3) The test subject shall don the enclosure while wearing the respirator selected according to section I. A. of this appendix. The respirator shall be properly adjusted and equipped with any type particulate filter(s).

(4) A second DeVilbiss Model 40 Inhalation Medication Nebulizer or equivalent is used to spray the fit test solution into the enclosure. This nebulizer shall be clearly marked to distinguish it from the screening test solution nebulizer.

(5) The fit test solution is prepared by adding 337.5 mg of Bitrex to 200 ml of a 5% salt (NaCl) solution in warm water.

(6) As before, the test subject shall breathe through his or her slightly open mouth with tongue extended, and be instructed to report if he/she tastes the bitter taste of Bitrex.

(7) The nebulizer is inserted into the hole in the front of the enclosure and an initial concentration of the fit test solution is sprayed into the enclosure using the same number of squeezes (either 10, 20 or 30 squeezes) based on the number of squeezes required to elicit a taste response as noted during the screening test.

(8) After generating the aerosol, the test subject shall be instructed to perform the exercises in section I. A. 14. of this appendix.

(9) Every 30 seconds the aerosol concentration shall be replenished using one half the number of squeezes used initially (e.g., 5, 10 or 15).

(10) The test subject shall indicate to the test conductor if at any time during the fit test the taste of Bitrex is detected. If the test subject does not report tasting the Bitrex, the test is passed.

(11) If the taste of Bitrex is detected, the fit is deemed unsatisfactory and the test is failed. A different respirator shall be tried and the entire test procedure is repeated (taste threshold screening and fit testing).

5. Irritant Smoke (Stannic Chloride) Protocol

This qualitative fit test uses a person's response to the irritating chemicals released in the ''smoke'' produced by a stannic chloride ventilation smoke tube to detect leakage into the respirator.

(a) General Requirements and Precautions

(1) The respirator to be tested shall be equipped with high efficiency particulate air (HEPA) or P100 series filter(s).

(2) Only stannic chloride smoke tubes shall be used for this protocol.

(3) No form of test enclosure or hood for the test subject shall be used.

(4) The smoke can be irritating to the eyes, lungs, and nasal passages. The test conductor shall take precautions to minimize the test subject's exposure to irritant smoke. Sensitivity varies, and certain individuals may respond to a greater degree to irritant smoke. Care shall be taken when performing the sensitivity screening checks that determine whether the test subject can detect irritant smoke to use only the minimum amount of smoke necessary to elicit a response from the test subject.

(5) The fit test shall be performed in an area with adequate ventilation to prevent exposure of the person conducting the fit test or the build-up of irritant smoke in the general atmosphere.

(b) Sensitivity Screening Check

The person to be tested must demonstrate his or her ability to detect a weak concentration of the irritant smoke.

(1) The test operator shall break both ends of a ventilation smoke tube containing stannic chloride, and attach one end of the smoke tube to a low flow air pump set to deliver 200 milliliters per minute, or an aspirator squeeze bulb. The test operator shall cover the other end of the smoke tube with a short piece of tubing to prevent potential injury from the jagged end of the smoke tube.

(2) The test operator shall advise the test subject that the smoke can be irritating to the eyes, lungs, and nasal passages and instruct the subject to keep his/her eyes closed while the test is performed.

(3) The test subject shall be allowed to smell a weak concentration of the irritant smoke before the respirator is donned to become familiar with its irritating properties and to determine if he/she can detect the irritating properties of the smoke. The test operator shall carefully direct a small amount of the irritant smoke in the test subject's direction to determine that he/she can detect it

(c) Irritant Smoke Fit Test Procedure

(1) The person being fit tested shall don the respirator without assistance, and perform the required user seal check(s).

(2) The test subject shall be instructed to keep his/her eyes closed.

(3) The test operator shall direct the stream of irritant smoke from the smoke tube toward the faceseal area of the test subject, using the low flow pump or the squeeze bulb. The test operator shall begin at least 12 inches from the facepiece and move the smoke stream around the whole perimeter of the mask. The operator shall gradually make two more passes around the perimeter of the mask, moving to within six inches of the respirator.

(4) If the person being tested has not had an involuntary response and/or detected the irritant smoke, proceed with the test exercises.

(5) The exercises identified in section I.A. 14. of this appendix shall be performed by the test subject while the respirator seal is being continually challenged by the smoke, directed around the perimeter of the respirator at a distance of six inches.

(6) If the person being fit tested reports detecting the irritant smoke at any time, the test is failed. The person being retested must repeat the entire sensitivity check and fit test procedure.

(7) Each test subject passing the irritant smoke test without evidence of a response (involuntary cough, irritation) shall be given a second sensitivity screening check, with the smoke from the same smoke tube used during the fit test, once the respirator has been removed, to determine whether he/she still reacts to the smoke. Failure to evoke a response shall void the fit test.

(8) If a response is produced during this second sensitivity check, then the fit test is passed.

C. QUANTITATIVE FIT TEST (QNFT) PROTOCOLS

The following quantitative fit testing procedures have been demonstrated to be acceptable: Quantitative fit testing using a non-hazardous test aerosol (such as corn oil, polyethylene glycol 400 [PEG 400], di-2-ethyl hexyl sebacate [DEHS], or sodium chloride) generated in a test chamber, and employing instrumentation to quantify the fit of the respirator; Quantitative fit testing using ambient aerosol as the test agent and appropriate instrumentation (condensation nuclei counter) to quantify the respirator fit; Quantitative fit testing using controlled negative pressure and appropriate instrumentation to measure the volumetric leak rate of a facepiece to quantify the respirator fit.

1. General

(a) The employer shall ensure that persons administering QNFT are able to calibrate equipment and perform tests properly, recognize invalid tests, calculate fit factors properly and ensure that test equipment is in proper working order.

(b) The employer shall ensure that QNFT equipment is kept clean, and is maintained and calibrated according to the manufacturer's instructions so as to operate at the parameters for which it was designed.

2. Generated Aerosol Quantitative Fit Testing Protocol

(a) Apparatus.

(1) Instrumentation. Aerosol generation, dilution, and measurement systems using particulates (corn oil, polyethylene glycol 400 [PEG 400], di-2-ethyl hexyl sebacate [DEHS] or sodium chloride) as test aerosols shall be used for quantitative fit testing.

(2) Test chamber. The test chamber shall be large enough to permit all test subjects to perform freely all required exercises without disturbing the test agent concentration or the measurement apparatus. The test chamber shall be equipped and constructed so that the test agent is effectively isolated from the ambient air, yet uniform in concentration throughout the chamber.

(3) When testing air-purifying respirators, the normal filter or cartridge element shall be replaced with a high efficiency particulate air (HEPA) or P100 series filter supplied by the same manufacturer.

(4) The sampling instrument shall be selected so that a computer record or strip chart record may be made of the test showing the rise and fall of the test agent concentration with each inspiration and expiration at fit factors of at least 2,000. Integrators or computers that integrate the amount of test agent penetration leakage into the respirator for each exercise may be used provided a record of the readings is made.

(5) The combination of substitute air-purifying elements, test agent and test agent concentration shall be such that the test subject is not exposed in excess of an established exposure limit for the test agent at any time during the testing process, based upon the length of the exposure and the exposure limit duration.

(6) The sampling port on the test specimen respirator shall be placed and constructed so that no leakage occurs around the port

(e.g., where the respirator is probed), a free air flow is allowed into the sampling line at all times, and there is no interference with the fit or performance of the respirator. The in-mask sampling device (probe) shall be designed and used so that the air sample is drawn from the breathing zone of the test subject, midway between the nose and mouth and with the probe extending into the facepiece cavity at least 1/4 inch.

(7) The test setup shall permit the person administering the test to observe the test subject inside the chamber during the test.

(8) The equipment generating the test atmosphere shall maintain the concentration of test agent constant to within a 10 percent variation for the duration of the test.

(9) The time lag (interval between an event and the recording of the event on the strip chart or computer or integrator) shall be kept to a minimum. There shall be a clear association between the occurrence of an event and its being recorded.

(10) The sampling line tubing for the test chamber atmosphere and for the respirator sampling port shall be of equal diameter and of the same material. The length of the two lines shall be equal.

(11) The exhaust flow from the test chamber shall pass through an appropriate filter (i.e., high efficiency particulate filter) before release.

(12) When sodium chloride aerosol is used, the relative humidity inside the test chamber shall not exceed 50 percent.

(13) The limitations of instrument detection shall be taken into account when determining the fit factor.

(14) Test respirators shall be maintained in proper working order and be inspected regularly for deficiencies such as cracks or missing valves and gaskets.

(b) Procedural Requirements.

(1) When performing the initial user seal check using a positive or negative pressure check, the sampling line shall be crimped closed in order to avoid air pressure leakage during either of these pressure checks.

(2) The use of an abbreviated screening QLFT test is optional. Such a test may be utilized in order to quickly identify poor fitting respirators that passed the positive and/or negative pressure test and reduce the amount of QNFT time. The use of the CNC QNFT instrument in the count mode is another optional method to obtain a quick estimate of fit and eliminate poor fitting respirators before going on to perform a full QNFT.

(3) A reasonably stable test agent concentration shall be measured in the test chamber prior to testing. For canopy or shower curtain types of test units, the determination of the test agent's stability may be established after the test subject has entered the test environment.

(4) Immediately after the subject enters the test chamber, the test agent concentration inside the respirator shall be measured to ensure that the peak penetration does not exceed 5 percent for a half mask or 1 percent for a full facepiece respirator.

(5) A stable test agent concentration shall be obtained prior to the actual start of testing.

(6) Respirator restraining straps shall not be over-tightened for testing. The straps shall be adjusted by the wearer without assistance from other persons to give a reasonably comfortable fit typical of normal use. The respirator shall not be adjusted once the fit test exercises begin.

(7) The test shall be terminated whenever any single peak penetration exceeds 5 percent for half masks and 1 percent for full facepiece respirators. The test subject shall be refitted and retested.

(8) Calculation of fit factors.

(i) The fit factor shall be determined for the quantitative fit test by taking the ratio of the average chamber concentration to the concentration measured inside the respirator for each test exercise except the grimace exercise.

(ii) The average test chamber concentration shall be calculated as the arithmetic average of the concen tration measured before and after each test (i.e., 7 exercises) or the arithmetic average of the concen tration measured before and after each exercise or the true average measured continuously during the respirator sample.

(iii) The concentration of the challenge agent inside the respirator shall be determined by one of the following methods:

(A) Average peak penetration method means the method of determining test agent penetration into the respirator utilizing a strip chart recorder, integrator, or computer. The agent penetration is determined by an average of the peak heights on the graph or by computer integration, for each exercise except the grimace exercise. Integrators or computers that calculate the actual test agent penetration into the respirator

for each exercise will also be considered to meet the requirements of the average peak penetration method.

(B) Maximum peak penetration method means the method of determining test agent penetration in the respirator as determined by strip chart recordings of the test. The highest peak penetration for a given exercise is taken to be representative of average penetration into the respirator for that exercise.

(C) Integration by calculation of the area under the individual peak for each exercise except the grimace exercise. This includes computerized integration.

(D) The calculation of the overall fit factor using individual exercise fit factors involves first converting the exercise fit factors to penetration values, determining the average, and then converting that result back to a fit factor. This procedure is described in the following equation:

$$\textit{Overall Fit Factor} = \frac{\textit{Number of exercises}}{\frac{1}{ff_1}+\frac{1}{ff_2}+\frac{1}{ff_3}+\frac{1}{ff_4}+\frac{1}{ff_5}+\frac{1}{ff_6}+\frac{1}{ff_7}+\frac{1}{ff_8}}$$

Where ff1, ff2, ff3, etc. are the fit factors for exercises 1, 2, 3, etc.

(9) The test subject shall not be permitted to wear a half mask or quarter facepiece respirator unless a minimum fit factor of 100 is obtained, or a full facepiece respirator unless a minimum fit factor of 500 is obtained.

(10) Filters used for quantitative fit testing shall be replaced whenever increased breathing resistance is encountered, or when the test agent has altered the integrity of the filter media.

3. Ambient aerosol condensation nuclei counter (CNC) quantitative fit testing protocol.

The ambient aerosol condensation nuclei counter (CNC) quantitative fit testing (Portacount™) protocol quantitatively fit tests respirators with the use of a probe. The probed respirator is only used for quantitative fit tests. A probed respirator has a special sampling device, installed on the respirator, that allows the probe to sample the air from inside the mask. A probed respirator is required for each make, style, model, and size that the employer uses and can be obtained from the respirator manufacturer or distributor. The CNC instrument manufacturer, TSI Inc., also provides probe attachments (TSI sampling adapters) that permit fit testing in an employee's own respirator. A minimum fit factor pass level of at least 100 is necessary for a half-mask respirator and a minimum fit factor pass level of at least 500 is required for a full facepiece negative pressure respirator. The entire screening and testing procedure shall be explained to the test subject prior to the conduct of the screening test.

(a) Portacount Fit Test Requirements.

(1) Check the respirator to make sure the sampling probe and line are properly attached to the facepiece and that the respirator is fitted with a particulate filter capable of preventing significant penetration by the ambient particles used for the fit test (e.g., NIOSH 42 *CFR* 84 series 100, series 99, or series 95 particulate filter) per manufacturer's instruction.

(2) Instruct the person to be tested to don the respirator for five minutes before the fit test starts. This purges the ambient particles trapped inside the respirator and permits the wearer to make certain the respirator is comfortable. This individual shall already have been trained on how to wear the respirator properly.

(3) Check the following conditions for the adequacy of the respirator fit: Chin properly placed; Adequate strap tension, not overly tightened; Fit across nose bridge; Respirator of proper size to span distance from nose to chin; Tendency of the respirator to slip; Self-observation in a mirror to evaluate fit and respirator position.

(4) Have the person wearing the respirator do a user seal check. If leakage is detected, determine the cause. If leakage is from a poorly fitting facepiece, try another size of the same model respirator, or another model of respirator.

(5) Follow the manufacturer's instructions for operating the Portacount and proceed with the test.

(6) The test subject shall be instructed to perform the exercises in section I. A. 14. of this appendix.

(7) After the test exercises, the test subject shall be questioned by the test conductor regarding the comfort of the respirator upon completion of the protocol. If it has become unacceptable, another model of respirator shall be tried.

(b) Portacount Test Instrument.

(1) The Portacount will automatically stop and calculate the overall fit factor for the entire set of exercises. The overall fit factor is what counts. The Pass or Fail message will indicate whether or not the test was successful. If the test was a Pass, the fit test is over.

(2) Since the pass or fail criterion of the Portacount is user programmable, the test operator

shall ensure that the pass or fail criterion meet the requirements for minimum respirator performance in this Appendix.

(3) A record of the test needs to be kept on file, assuming the fit test was successful. The record must contain the test subject's name; overall fit factor; make, model, style, and size of respirator used; and date tested.

4. Controlled negative pressure (CNP) quantitative fit testing protocol.

The CNP protocol provides an alternative to aerosol fit test methods. The CNP fit test method technology is based on exhausting air from a temporarily sealed respirator facepiece to generate and then maintain a constant negative pressure inside the facepiece. The rate of air exhaust is controlled so that a constant negative pressure is maintained in the respirator during the fit test. The level of pressure is selected to replicate the mean inspiratory pressure that causes leakage into the respirator under normal use conditions. With pressure held constant, air flow out of the respirator is equal to air flow into the respirator. Therefore, measurement of the exhaust stream that is required to hold the pressure in the temporarily sealed respirator constant yields a direct measure of leakage air flow into the respirator. The CNP fit test method measures leak rates through the facepiece as a method for determining the facepiece fit for negative pressure respirators. The CNP instrument manufacturer Dynatech Nevada also provides attachments (sampling manifolds) that replace the filter cartridges to permit fit testing in an employee's own respirator. To perform the test, the test subject closes his or her mouth and holds his/her breath, after which an air pump removes air from the respirator facepiece at a pre-selected constant pressure. The facepiece fit is expressed as the leak rate through the facepiece, expressed as milliliters per minute. The quality and validity of the CNP fit tests are determined by the degree to which the in-mask pressure tracks the test pressure during the system measurement time of approximately five seconds. Instantaneous feedback in the form of a real-time pressure trace of the in-mask pressure is provided and used to determine test validity and quality. A minimum fit factor pass level of 100 is necessary for a half-mask respirator and a minimum fit factor of at least 500 is required for a full facepiece respirator. The entire screening and testing procedure shall be explained to the test subject prior to the conduct of the screening test.

(a) CNP Fit Test Requirements.

(1) The instrument shall have a non-adjustable test pressure of 15.0 mm water pressure.

(2) The CNP system defaults selected for test pressure shall be set at–15 mm of water (–0.58 inches of water) and the modeled inspiratory flow rate shall be 53.8 liters per minute for performing fit tests.

(Note: CNP systems have built-in capability to conduct fit testing that is specific to unique work rate, mask, and gender situations that might apply in a specific workplace. Use of system default values, which were selected to represent respirator wear with medium cartridge resistance at a low-moderate work rate, will allow inter-test comparison of the respirator fit.)

(3) The individual who conducts the CNP fit testing shall be thoroughly trained to perform the test.

(4) The respirator filter or cartridge needs to be replaced with the CNP test manifold. The inhalation valve downstream from the manifold either needs to be temporarily removed or propped open.

(5) The test subject shall be trained to hold his or her breath for at least 20 seconds.

(6) The test subject shall don the test respirator without any assistance from the individual who conducts the CNP fit test.

(7) The QNFT protocol shall be followed according to section I. C. 1. of this appendix with an exception for the CNP test exercises.

(b) CNP Test Exercises.

(1) Normal breathing. In a normal standing position, without talking, the subject shall breathe normally for 1 minute. After the normal breathing exercise, the subject needs to hold head straight ahead and hold his or her breath for 10 seconds during the test measurement.

(2) Deep breathing. In a normal standing position, the subject shall breathe slowly and deeply for 1 minute, being careful not to hyperventilate. After the deep breathing exercise, the subject shall hold his or her head straight ahead and hold his or her breath for 10 seconds during test measurement.

(3) Turning head side to side. Standing in place, the subject shall slowly turn his or her head from side to side between the extreme positions on each side for 1 minute. The head shall be held at each extreme momentarily so the subject can inhale at each side. After the turning head side to side exercise, the subject needs to

hold head full left and hold his or her breath for 10 seconds during test measurement. Next, the subject needs to hold head full right and hold his or her breath for 10 seconds during test measurement.

(4) Moving head up and down. Standing in place, the subject shall slowly move his or her head up and down for 1 minute. The subject shall be instructed to inhale in the up position (i.e., when looking toward the ceiling). After the moving head up and down exercise, the subject shall hold his or her head full up and hold his or her breath for 10 seconds during test measurement. Next, the subject shall hold his or her head full down and hold his or her breath for 10 seconds during test measurement.

(5) Talking. The subject shall talk out loud slowly and loud enough so as to be heard clearly by the test conductor. The subject can read from a prepared text such as the Rainbow Passage, count backward from 100, or recite a memorized poem or song for 1 minute. After the talking exercise, the subject shall hold his or her head straight ahead and hold his or her breath for 10 seconds during the test measurement.

(6) Grimace. The test subject shall grimace by smiling or frowning for 15 seconds.

(7) Bending Over. The test subject shall bend at the waist as if he or she were to touch his or her toes for 1 minute. Jogging in place shall be substituted for this exercise in those test environments such as shroud-type QNFT units that prohibit bending at the waist. After the bending over exercise, the subject shall hold his or her head straight ahead and hold his or her breath for 10 seconds during the test measurement.

(8) Normal Breathing. The test subject shall remove and re-don the respirator within a one-minute period. Then, in a normal standing position, without talking, the subject shall breathe normally for 1 minute. After the normal breathing exercise, the subject shall hold his or her head straight ahead and hold his or her breath for 10 seconds during the test measurement. After the test exercises, the test subject shall be questioned by the test conductor regarding the comfort of the respirator upon completion of the protocol. If it has become unacceptable, another model of a respirator shall be tried.

(c) CNP Test Instrument.

(1) The test instrument shall have an effective audio warning device when the test subject fails to hold his or her breath during the test. The test shall be terminated whenever the test subject failed to hold his or her breath. The test subject may be refitted and retested.

(2) A record of the test shall be kept on file, assuming the fit test was successful. The record must contain the test subject's name; overall fit factor; make, model, style and size of respirator used; and date tested.

Part II. New Fit Test Protocols

A. Any person may submit to OSHA an application for approval of a new fit test protocol. If the application meets the following criteria, OSHA will initiate a rulemaking proceeding under section 6(b)(7) of the OSH Act to determine whether to list the new protocol as an approved protocol in this Appendix A.

B. The application must include a detailed description of the proposed new fit test protocol. This application must be supported by either:

1. A test report prepared by an independent government research laboratory (e.g., Lawrence Livermore National Laboratory, Los Alamos National Laboratory, the National Institute for Standards and Technology) stating that the laboratory has tested the protocol and had found it to be accurate and reliable; or

2. An article that has been published in a peer-reviewed industrial hygiene journal describing the protocol and explaining how test data support the protocol's accuracy and reliability.

C. If OSHA determines that additional information is required before the Agency commences a rulemaking proceeding under this section, OSHA will so notify the applicant and afford the applicant the opportunity to submit the supplemental information. Initiation of a rulemaking proceeding will be deferred until OSHA has received and evaluated the supplemental information.

APPENDIX B-1 TO § 1910.134: USER SEAL CHECK PROCEDURES (MANDATORY)

The individual who uses a tight-fitting respirator is to perform a user seal check to ensure that an adequate seal is achieved each time the respirator is put on. Either the positive and negative pressure checks listed in this appendix, or the respirator manufacturer's recommended user seal check method shall be used. User seal checks are not substitutes for qualitative or quantitative fit tests.

I. Facepiece Positive and/or Negative Pressure Checks

A. *Positive pressure check.* Close off the exhalation valve and exhale gently into the facepiece. The face fit is considered

satisfactory if a slight positive pressure can be built up inside the facepiece without any evidence of outward leakage of air at the seal. For most respirators this method of leak testing requires the wearer to first remove the exhalation valve cover before closing off the exhalation valve and then carefully replacing it after the test.

B. *Negative pressure check.* Close off the inlet opening of the canister or cartridge(s) by covering with the palm of the hand(s) or by replacing the filter seal(s), inhale gently so that the facepiece collapses slightly, and hold the breath for ten seconds. The design of the inlet opening of some cartridges cannot be effectively covered with the palm of the hand. The test can be performed by covering the inlet opening of the cartridge with a thin latex or nitrile glove. If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the tightness of the respirator is considered satisfactory.

II. Manufacturer's Recommended User Seal Check Procedures

The respirator manufacturer's recommended procedures for performing a user seal check may be used instead of the positive and/or negative pressure check procedures provided that the employer demonstrates that the manufacturer's procedures are equally effective.

APPENDIX B-2 TO § 1910.134: RESPIRATOR CLEANING PROCEDURES (MANDATORY)

These procedures are provided for employer use when cleaning respirators. They are general in nature, and the employer as an alternative may use the cleaning recommendations provided by the manufacturer of the respirators used by their employees, provided such procedures are as effective as those listed here in Appendix B-2. Equivalent effectiveness simply means that the procedures used must accomplish the objectives set forth in Appendix B-2, i.e., must ensure that the respirator is properly cleaned and disinfected in a manner that prevents damage to the respirator and does not cause harm to the user.

I. Procedures for Cleaning Respirators

A. Remove filters, cartridges, or canisters. Disassemble facepieces by removing speaking diaphragms, demand and pressure-demand valve assemblies, hoses, or any components recommended by the manufacturer. Discard or repair any defective parts.

B. Wash components in warm (43 C [110 F] maximum) water with a mild detergent or with a cleaner recommended by the manufacturer. A stiff bristle (not wire) brush may be used to facilitate the removal of dirt.

C. Rinse components thoroughly in clean, warm (43 C [110 F] maximum), preferably running water. Drain.

D. When the cleaner used does not contain a disinfecting agent, respirator components should be immersed for two minutes in one of the following:

1. Hypochlorite solution (50 ppm of chlorine) made by adding approximately one milliliter of laundry bleach to one liter of water at 43 C (110 F); or,

2. Aqueous solution of iodine (50 ppm iodine) made by adding approximately 0.8 milliliters of tincture of iodine (6–8 grams ammonium and/or potassium iodide/100 cc of 45% alcohol) to one liter of water at 43 C (110 F); or,

3. Other commercially available cleansers of equivalent disinfectant quality when used as directed, if their use is recommended or approved by the respirator manufacturer.

E. Rinse components thoroughly in clean, warm (43 C [110 F] maximum), preferably running water. Drain. The importance of thorough rinsing cannot be overemphasized. Detergents or disinfectants that dry on facepieces may result in dermatitis. In addition, some disinfectants may cause deterioration of rubber or corrosion of metal parts if not completely removed.

F. Components should be hand-dried with a clean lint-free cloth or air-dried.

G. Reassemble facepiece, replacing filters, cartridges, and canisters where necessary.

H. Test the respirator to ensure that all components work properly.

APPENDIX C TO § 1910.134: OSHA RESPIRATOR MEDICAL EVALUATION QUESTIONNAIRE (MANDATORY)

To the employer: Answers to questions in Section 1, and to question 9 in Section 2 of Part A, do not require a medical examination.

To the employee: Can you read (circle one): Yes / No

Your employer must allow you to answer this questionnaire during normal working hours, or at a time and place that is convenient to you. To maintain your confidentiality, your employer or supervisor must not look at or review your answers, and your employer must tell you how to deliver or send this questionnaire to the health care professional who will review it.

Part A. Section 1. (Mandatory) The following information must be provided by every employee who has been selected to use any type of respirator (please print).

1. Today's date: _____
2. Your name: _____
3. Your age (to nearest year): _____
4. Sex (circle one): Male/Female
5. Your height: ____ft. ____in.
6. Your weight: ____ lbs.
7. Your job title:_____

8. A phone number where you can be reached by the health care professional who reviews this questionnaire (include the Area Code):
   _____
9. The best time to phone you at this number: _____
10. Has your employer told you how to contact the health care professional who will review this questionnaire (circle one): Yes / No
11. Check the type of respirator you will use (you can check more than one category):
    a. ____ N, R, or P disposable respirator (filter-mask, non-cartridge type only).
    b. ____ Other type (for example, half- or full-facepiece type, powered-air purifying, supplied-air, self-contained breathing apparatus).
12. Have you worn a respirator (circle one): Yes / No

If "yes," what type(s): _____

Part A. Section 2. (Mandatory) Questions 1 through 9 below must be answered by every employee who has been selected to use any type of respirator (please circle "yes" or "no").

1. Do you currently smoke tobacco, or have you smoked tobacco in the last month: Yes / No
2. Have you ever had any of the following conditions?
   a. Seizures (fits): Yes / No
   b. Diabetes (sugar disease): Yes / No
   c. Allergic reactions that interfere with your breathing: Yes / No
   d. Claustrophobia (fear of closed-in places): Yes / No
   e. Trouble smelling odors: Yes / No
3. Have you ever had any of the following pulmonary or lung problems?
   a. Asbestosis: Yes / No
   b. Asthma: Yes / No
   c. Chronic bronchitis: Yes / No
   d. Emphysema: Yes / No
   e. Pneumonia: Yes / No
   f. Tuberculosis: Yes / No
   g. Silicosis: Yes / No
   h. Pneumothorax (collapsed lung): Yes / No
   i. Lung cancer: Yes / No
   j. Broken ribs: Yes / No
   k. Any chest injuries or surgeries: Yes / No
   l. Any other lung problem that you've been told about: Yes / No
4. Do you currently have any of the following symptoms of pulmonary or lung illness?
   a. Shortness of breath: Yes / No
   b. Shortness of breath when walking fast on level ground or walking up a slight hill or incline: Yes / No
   c. Shortness of breath when walking with other people at an ordinary pace on level ground: Yes / No
   d. Have to stop for breath when walking at your own pace on level ground: Yes / No
   e. Shortness of breath when washing or dressing yourself: Yes / No
   f. Shortness of breath that interferes with your job: Yes / No
   g. Coughing that produces phlegm (thick sputum): Yes / No
   h. Coughing that wakes you early in the morning: Yes / No
   i. Coughing that occurs mostly when you are lying down: Yes / No
   j. Coughing up blood in the last month: Yes / No
   k. Wheezing: Yes / No
   l. Wheezing that interferes with your job: Yes / No
   m. Chest pain when you breathe deeply: Yes / No
   n. Any other symptoms that you think may be related to lung problems: Yes / No
5. Have you ever had any of the following cardiovascular or heart problems?
   a. Heart attack: Yes / No
   b. Stroke: Yes / No
   c. Angina: Yes / No
   d. Heart failure: Yes / No
   e. Swelling in your legs or feet (not caused by walking): Yes / No
   f. Heart arrhythmia (heart beating irregularly): Yes / No
   g. High blood pressure: Yes / No
   h. Any other heart problem that you've been told about: Yes / No
6. Have you ever had any of the following cardiovascular or heart symptoms?
   a. Frequent pain or tightness in your chest: Yes / No
   b. Pain or tightness in your chest during physical activity: Yes / No
   c. Pain or tightness in your chest that interferes with your job: Yes / No
   d. In the past two years, have you noticed your heart skipping or missing a beat: Yes / No
   e. Heartburn or indigestion that is not related to eating: Yes / No
   f. Any other symptoms that you think may be related to heart or circulation problems: Yes / No
7. Do you currently take medication for any of the following problems?
   a. Breathing or lung problems: Yes / No
   b. Heart trouble: Yes / No
   c. Blood pressure: Yes / No
   d. Seizures (fits): Yes / No
8. If you've used a respirator, have you ever had any of the following problems? (If you've never used a respirator, check the following space and go to question 9:)

a. Eye irritation: Yes / No
b. Skin allergies or rashes: Yes / No
c. Anxiety: Yes / No
d. General weakness or fatigue: Yes / No
e. Any other problem that interferes with your use of a respirator: Yes / No

9. Would you like to talk to the health care professional who will review this questionnaire about your answers to this questionnaire: Yes / No

Questions 10 to 15 below must be answered by every employee who has been selected to use either a full-facepiece respirator or a self-contained breathing apparatus (SCBA). For employees who have been selected to use other types of respirators, answering these questions is voluntary.

10. Have you ever lost vision in either eye (temporarily or permanently): Yes / No
11. Do you currently have any of the following vision problems?
    a. Wear contact lenses: Yes / No
    b. Wear glasses: Yes / No
    c. Color blind: Yes / No
    d. Any other eye or vision problem: Yes / No
12. Have you ever had an injury to your ears, including a broken ear drum: Yes / No
13. Do you currently have any of the following hearing problems?
    a. Difficulty hearing: Yes / No
    b. Wear a hearing aid: Yes / No
    c. Any other hearing or ear problem: Yes / No
14. Have you ever had a back injury: Yes / No
15. Do you currently have any of the following musculoskeletal problems?
    a. Weakness in any of your arms, hands, legs, or feet: Yes / No
    b. Back pain: Yes / No
    c. Difficulty fully moving your arms and legs: Yes / No
    d. Pain or stiffness when you lean forward or backward at the waist: Yes / No
    e. Difficulty fully moving your head up or down: Yes / No
    f. Difficulty fully moving your head side to side: Yes / No
    g. Difficulty bending at your knees: Yes / No
    h. Difficulty squatting to the ground: Yes / No
    i. Climbing a flight of stairs or a ladder carrying more than 25 lbs: Yes / No
    j. Any other muscle or skeletal problem that interferes with using a respirator: Yes / No

Part B Any of the following questions, and other questions not listed, may be added to the questionnaire at the discretion of the health care professional who will review the questionnaire.

1. In your present job, are you working at high altitudes (over 5,000 feet) or in a place that has lower than normal amounts of oxygen: Yes / No
   If '"yes," do you have feelings of dizziness, shortness of breath, pounding in your chest, or other symptoms when you're working under these conditions: Yes / No
2. At work or at home, have you ever been exposed to hazardous solvents, hazardous airborne chemicals (e.g., gases, fumes, or dust), or have you come into skin contact with hazardous chemicals: Yes / No
   If ''yes," name the chemicals if you know them:
   _____
3. Have you ever worked with any of the materials, or under any of the conditions, listed below:
   a. Asbestos: Yes / No
   b. Silica (e.g., in sandblasting): Yes / No
   c. Tungsten/cobalt (e.g., grinding or welding this material): Yes / No
   d. Beryllium: Yes / No
   e. Aluminum: Yes / No
   f. Coal (for example, mining): Yes / No
   g. Iron: Yes / No
   h. Tin: Yes / No
   i. Dusty environments: Yes / No
   j. Any other hazardous exposures: Yes / No
      If "yes," describe these exposures: _____
4. List any second jobs or side businesses you have: _____
5. List your previous occupations: _____
6. List your current and previous hobbies: _____
7. Have you been in the military services? Yes / No
   If "yes," were you exposed to biological or chemical agents (either in training or combat): Yes / No
8. Have you ever worked on a HAZMAT team? Yes / No
9. Other than medications for breathing and lung problems, heart trouble, blood pressure, and seizures mentioned earlier in this questionnaire, are you taking any other medications for any reason (including over-the-counter medications): Yes / No
   If "yes," name the medications if you know them:_____
10. Will you be using any of the following items with your respirator(s)?
    a. HEPA Filters: Yes / No
    b. Canisters (for example, gas masks): Yes / No
    c. Cartridges: Yes / No
11. How often are you expected to use the respirator(s) (circle "yes" or "no" for all answers that apply to you)?
    a. Escape only (no rescue): Yes / No
    b. Emergency rescue only: Yes / No
    c. Less than 5 hours per week: Yes / No
    d. Less than 2 hours per day: Yes / No

e. 2 to 4 hours per day: Yes / No
f. Over 4 hours per day: Yes / No

12. During the period you are using the respirator(s), is your work effort:
    a. Light (less than 200 kcal per hour): Yes / No
    If "yes," how long does this period last during the average shift: ____ hrs. ____ mins.
    Examples of a light work effort are sitting while writing, typing, drafting, or performing light assembly work; or standing while operating a drill press (1-3 lbs.) or controlling machines.
    b. Moderate (200 to 350 kcal per hour): Yes / No
    If "yes," how long does this period last during the average shift: _____ hrs. _____l mins.
    Examples of moderate work effort are sitting while nailing or filing; driving a truck or bus in urban traffic; standing while drilling, nailing, performing assembly work, or transferring a moderate load (about 35 lbs.) at trunk level; walking on a level surface about 2 mph or down a 5-degree grade about 3 mph; or pushing a wheelbarrow with a heavy load (about 100 lbs.) on a level surface.
    c. Heavy (above 350 kcal per hour): Yes / No
    If "yes," how long does this period last during the average shift: ____ hrs. ____ mins.
    Examples of heavy work are lifting a heavy load (about 50 lbs.) from the floor to your waist or shoulder; working on a loading dock; shoveling; standing while bricklaying or chipping castings; walking up an 8-degree grade about 2 mph; climbing stairs with a heavy load (about 50 lbs.).
13. Will you be wearing protective clothing and/or equipment (other than the respirator) when you're using your respirator: Yes / No

If ''yes," describe this protective clothing and/or equipment: _____

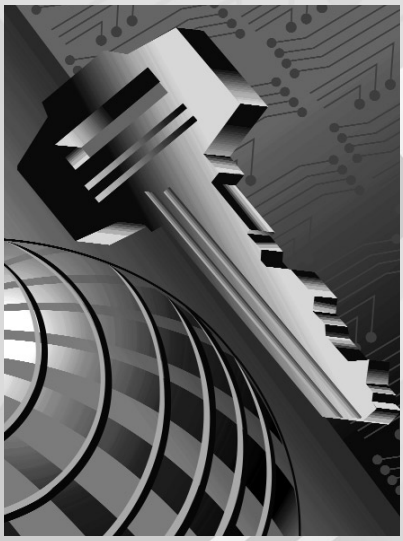
14. Will you be working under hot conditions (temperature exceeding 77__F): Yes / No
15. Will you be working under humid conditions: Yes / No
16. Describe the work you'll be doing while you're using your respirator(s): _____
17. Describe any special or hazardous conditions you might encounter when you're using your respirator(s) (for example, confined spaces, life-threatening gases): _____
18. Provide the following information, if you know it, for each toxic substance that you'll be exposed to when you're using your respirator(s):
    Name of the first toxic substance:
    _____
    Estimated maximum exposure level per shift:
    _____
    Duration of exposure per shift
    _____
    Name of the second toxic substance:
    _____
    Estimated maximum exposure level per shift:
    _____
    Duration of exposure per shift: _____
    Name of the third toxic substance:
    _____
    Estimated maximum exposure level per shift:
    _____
    Duration of exposure per shift:_____
    The name of any other toxic substances that you'll be exposed to while using your respirator:
    _____
19. Describe any special responsibilities you'll have while using your respirator(s) that may affect the safety and well-being of others (for example, rescue, security): _____

APPENDIX D TO § 1910.134 (MANDATORY) INFORMATION FOR EMPLOYEES USING RESPIRATORS WHEN NOT REQUIRED UNDER THE STANDARD

Respirators are an effective method of protection against designated hazards when properly selected and worn. Respirator use is encouraged, even when exposures are below the exposure limit, to provide an additional level of comfort and protection for workers. However, if a respirator is used improperly or not kept clean, the respirator itself can become a hazard to the worker. Sometimes, workers may wear respirators to avoid exposures to hazards, even if the amount of hazardous substance does not exceed the limits set by OSHA standards. If your employer provides respirators for your voluntary use, of if you provide your own respirator, you need to take certain precautions to be sure that the respirator itself does not present a hazard.

You should do the following:

1. Read and heed all instructions provided by the manufacturer on use, maintenance, cleaning and care, and warnings regarding the respirators limitations.
2. Choose respirators certified for use to protect against the contaminant of concern. NIOSH, the National Institute for Occupational Safety and Health of the U.S. Department of Health and Human Services, certifies respirators. A label or statement of certification should appear on the respirator or respirator packaging. It will tell you what the respirator is designed for and how much it will protect you.
3. Do not wear your respirator into atmospheres containing contaminants for which your respirator is not designed to protect against. For example, a respirator designed to filter dust particles will not protect you against gases, vapors, or very small solid particles of fumes or smoke.
4. Keep track of your respirator so that you do not mistakenly use someone else's respirator.



Occupational Health and Safety Professions

Part VI

Chapter 23

The Industrial Hygienist

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This chapter discusses the background and definition of industrial hygiene, the interrelationship of the industrial hygienist and other occupational groups, occupational settings in which industrial hygienists function, and training programs. The reader will be able to define industrial hygiene, describe the types of jobs and settings in which industrial hygienists work, and identify specific types of educational curricula, resources, and professional organizations that deal with industrial hygiene.

BACKGROUND

Industrial hygienists are scientists, engineers, and public health professionals committed to protecting the health of people in the workplace and the community. Industrial hygienists must be competent in a variety of scientific fields—principally chemistry, engineering, physics, toxicology and biology—as well as the fundamentals of occupational medicine. Trained initially in one of these fields, most industrial hygienists have acquired by experience and postgraduate study a knowledge of the other allied disciplines.

In traditional industrial organizations, industrial hygienists were required to relate to personnel in other functions including research and development, medical, management, safety, and production. Although the working relationships were close, it was understood that the industrial hygienist was not expected to have expertise in these areas. In today's downsized organization, the industrial hygienist may also act as the safety or environmental professional. Flattened management structures and the use of self-directed work teams have created the need for flexible industrial hygienists who understand not only technical and scientific issues, but also production and research concerns. Hygienists at all levels participate in management of cross-functional projects that draw on the expertise of all team members to develop and maintain a safe and healthful work environment. One of the

challenges for this generation of industrial hygienists is maintaining a high level of technical expertise while broadening their roles in the activities just described.

Definition of Industrial Hygiene

The American Industrial Hygiene Association (AIHA) has defined industrial hygiene as the anticipation, recognition, evaluation, and control of environmental factors arising in or from the workplace that may result in injury, illness, or impairment, or affect the well-being of workers and members of the community. The AIHA describes industrial hygienists as

> *scientists and engineers committed to protecting the health and safety of people in the workplace and the community. Industrial hygiene is considered a "science," but it is also an art that involves judgment, creativity and human interaction. The goal of the industrial hygienist is to keep workers, their families, and the community healthy and safe. They play a vital part in ensuring that federal, state, and local laws and regulations are followed in the work environment.*

Typical roles of the industrial hygienist include:

- ➢ *Investigating and examining the workplace for hazards and potential dangers*
- ➢ *Making recommendations on improving the safety of workers and the surrounding community*
- ➢ *Conducting scientific research to provide data on possible harmful conditions in the workplace*
- ➢ *Developing techniques to anticipate and control potentially dangerous situations in the workplace and the community*
- ➢ *Training and educating the community about job-related risks*
- ➢ *Advising government officials and participating in the development of regulations to ensure the health and safety of workers and their families*
- ➢ *Ensuring that workers are properly following health and safety procedures*

To develop the depth of knowledge necessary to excel in industrial hygiene, many practitioners specialize in specific sub-disciplines, such as toxicology, epidemiology, chemistry, ergonomics, acoustics, ventilation engineering, and statistics, among others. Industrial hygienists often find their work overlapping with that of safety professionals, health physicists, engineers, and others in the fields of air pollution, water pollution, solid waste disposal, and disaster planning.

The industrial hygienist also makes contributions in employee education and training, law and product liability, sales, labeling, and public information. Other health professionals, including physicians, nurses, paramedics, and emergency medical technicians may at times assume some industrial hygiene functions.

JOB DESCRIPTIONS

The job descriptions and titles of industrial hygiene personnel may be somewhat similar to those of safety personnel. In the recent past they have evolved to reflect more team oriented or entrepreneurial approaches to safety and health management. However, many job descriptions have common elements that loosely coalesce around the following themes.

The entry-level employee may be called a safety or health technologist or technician. In this function the employee will evaluate hazards and operations using a few simple instruments, and investigate minor incidents involving occupational health issues.

Occupational Safety and Health Technologist

In 1976 the American Board of Industrial Hygiene (ABIH), in recognition of the growing group of technologists engaged in industrial hygiene activities, established an industrial hygiene technologist certification program. The technologist was recognized as someone who had acquired proficiency in an aspect or phase of industrial hygiene and who performed his or her duties under the supervision of an industrial hygienist. The designation certified industrial hygiene technologist was awarded after the applicant passed an examination. In 1985 the ABIH and the Board of Certified Safety Professionals joined to operate this program through a joint committee, and the certification was changed to Occupational Health and Safety Technologist (OHST). There are currently approximately 1,192 OHSTs.

Occupational Health and Safety Technologists perform occupational health and safety activities on a full-time or part-time basis as part of their job duties. Such duties may be ancillary to other job functions. Some examples of occupational health and safety activities are safety inspections; industrial hygiene monitoring; organizing and conducting health and safety training; investigating and maintaining records of occupational accidents, incidents, injuries, and illnesses; and similar functions. Candidates for the OHST need five years experience in occupational health or safety activities that comprise at least 35 percent of job duties, must pass the OHST examination, and complete Certification Maintenance requirements every five years. Candidates may substitute college courses in health and safety or an associate degree or higher in certain disciplines for up to two years of the experience requirement. The OHST examination deals with basic and applied science, laws, regulations and standards, control concepts, investigation (post-event), survey and inspection techniques, data computation and record keeping, education, training, and instruction.

Industrial hygiene technicians and technologists can function efficiently in their limited technical area. They may take samples and make measurements in the facility or community. Their data and observations can be used to provide information for an industrial hygiene plan or program.

The duties of the technician require thoroughness, dependability, and a concern for the accuracy of the data

being collected. They should be given a detailed outline of the duties, and have reference manuals readily available. Technicians must see the relevance and value of their efforts; these should be reflected in the technician's salary and in workplace structure. The industrial hygiene technician is part of the team in which the technician and industrial hygienist share responsibility.

Technology changes and adds new problems to the old ones. Rarely are old hazards totally controlled. New problems call for new approaches, new instrumentation, and new ways of recording, compiling, and integrating data. Consider, for example, the advent of computerized exposure monitoring databases accessible through intranets and the Internet, which allow much quicker sharing of data. Technicians must be willing to adjust to such changes, and may be able to become specialists in their own right. Some may remain technicians, but many will move on to become industrial hygienists.

Industrial Hygienist

The employee at the next higher level, typically titled an industrial hygienist, functions similarly to the safety engineer. The industrial hygienist carries out more detailed studies of incidents; prepares recommendations and other reports; reviews new processes, machinery, and layouts from a health (or safety) viewpoint; promotes occupational health and safety education; and advises management about health hazards, industrial hygiene practices, procedures, and equipment needs.

The industrial hygiene manager or supervisor has traditionally had duties similar to those of a safety director, and may manage the entire industrial hygiene program. In the last decade many companies have collapsed the duties of safety and industrial hygiene manager into one function or position, and have sometimes added responsibility for other functions such as environmental safety, facility security, or risk management. This has sometimes required that routine activities such as exposure monitoring be delegated to personnel at lower levels. Such facilities may also have concurrently reduced the size of their safety/health/environmental departments, and instead may rely on outside contractors to provide the personnel and skills necessary for various industrial hygiene projects. Other facilities may put the burden of more technical exposure assessment back on the "manager," who again becomes, in some cases, a "hands-on hygienist," without the assistance of a staff to support him or her with numerous responsibilities. Because they have the most experience and expertise, managers in these situations are likely to be called on to do the most complicated and advanced industrial hygiene tasks. Such a high degree of responsibility reinforces the need for a recognized level of competence in industrial hygiene personnel, which is provided by the certification mechanism.

Many certified industrial hygienists are also certified safety professionals and vice versa. Proficiency in industrial hygiene, by examination and by experience, follows a route roughly comparable to that of occupational safety. Moreover, the type of organization that employs the industrial hygienist or safety professional often requires similar skills of each. While many industrial hygienists work in private industry, many find positions in other types of endeavors that require particular skill sets.

Government industrial hygienists may find that a diplomatic demeanor and well-developed interpersonal skills are among their most important assets. Similarly consultants must have the flexibility to work with a wide range of clients and demands. Universities require professional capabilities in research, teaching, and program administration. University industrial hygienists need to be well versed in occupational and environmental issues to deal with the many complex problems involving chemical safety, worker safety, student safety, buildings and ground worker safety, building workers, and in those institutions affiliated with medical schools, hospital health and safety. In such settings there are many opportunities for hands-on industrial hygiene work. Campus health and safety staff, for example, may conduct many laboratory inspections that include field measurements such as hood flow rate and face velocity. They work with contractors doing renovation projects and may need to make air and ventilation measurements. Radiation safety staff also do measurement surveys of areas where radiation sources are used.

Labor union industrial hygienists may handle technical inquiries from contractors, union officials, and union members; develop curricula for training and regulatory analyses and testimony; perform job site visits, inspections, and audits; and conduct presentations. Typically they do little actual sampling. Writing and communication skills are essential, as are good interpersonal skills (used in listening to workers and in conflict resolution).

Industrial Hygienist-in-Training (IHIT)

This designation was formerly part of the ABIH's certification program. It was issued after the candidate passed the core examination, then the first of two exams taken to become a CIH. The last core exam was given by the ABIH in Fall, 2001. Now the procedure to become a CIH has changed to one in which the candidate takes only one, comprehensive examination. Those currently holding the IHIT certification (466 in number) have six years (from date of issue) before their certificates expire. Before then they must take the comprehensive exam and become CIHs. All of the other experience and education requirements to take the CIH exam still apply.

Historically, the ABIH had issued the IHIT category in 1972 because it then recognized that people with degrees and only one year of work experience wanted to take the core examination before completing the five years of experience in IH necessary to take the comprehensive exam.

During the first years of his or her career, the IHIT learned about the elements of organization and management. He/she also learned to understand flowcharts and blueprints as part of developing skills in anticipating, recognizing, evaluating, and controlling occupational health hazards. IHITs find that increasing emphasis is placed on communication skills, and should have been encouraged to draft replies to letters, write reports, and prepare oral presentations for editing by the supervisor.

If the IHIT has not already done so, he or she should become involved in the local section or chapter of the most appropriate professional association. The IHIT should attend meetings and work on committees, and should begin to meet other professionals outside the immediate workplace.

Industrial Hygiene Functions

Because they have more generalized skills, industrial hygienists should be able to make independent decisions. The industrial hygienist decides what information is available, what additional facts are needed, and how they will be used or acquired.

FUNCTIONS

More than 40 years ago, Radcliffe et al. (1959) described the sphere of responsibility of industrial hygienists, which remains relevant today. They stated that the industrial hygienist will:

- ➢ Direct the industrial hygiene program
- ➢ Examine the work environment

Study work operations and processes and obtain full details of the nature of the work, materials, and equipment used, products and by-products, number and sex of employees, and hours of work.

Make appropriate measurements to determine the magnitude of exposure or nuisance to workers and the public, devise methods and select instruments suitable for such measurements, personally (or through others under direct supervision) conduct such measurements, and study and test material associated with the work operations.

Using chemical and physical means, study the results of tests of biological materials, such as blood and urine, when such examination will aid in determining the extent of exposure.

- ➢ Interpret results of the examination of the environment in terms of its ability to impair health, nature of health impairment, workers' efficiency, and community nuisance or damage, and present specific conclusions to appropriate parties such as management, health officials, and employee representatives
- ➢ Make specific decisions as to the need for or effectiveness of control measures and, when necessary, advise as to the procedures that are suitable and effective for both the work environment and the general environment.
- ➢ Prepare rules, regulations, standards, and procedures for the healthful conduct of work and the prevention of nuisance in the community
- ➢ Present expert testimony before courts of law, hearing boards, workers' compensation commissions, regulatory agencies, and legally appointed investigative bodies
- ➢ Prepare appropriate text for labels and precautionary information for materials and products to be used by workers and the public
- ➢ Conduct programs for the education of workers and the public in the prevention of occupational disease and community nuisance
- ➢ Conduct epidemiological studies of workers and industries to discover the presence of occupational disease and establish or improve Threshold Limit Values® or standards for the maintenance of health and efficiency
- ➢ Conduct research to advance knowledge concerning the effects of occupation on health and means of preventing occupational health impairment, community air pollution, noise, nuisance, and related problems

The industrial hygienist should be able to determine whether there are alternative solutions to a problem. Obviously, leadership and management skills are required.

Few problems are so unique that peer acceptance is not required. Thus, the industrial hygienist must be able to work with other industrial hygienists in the same functional area, whether in industry, government, labor unions, insurance, consulting, or teaching.

The industrial hygienist should also have the experience, knowledge, and capability to specify corrective procedures to minimize or control environmental health hazards.

Many organizations try to "grow their own industrial hygienist"—that is, taking someone from inside the organization, with some scientific background and a knowledge of the firm's products, and exposing him or her to a crash program in industrial hygiene. An organization initiating an industrial hygiene effort must recognize that knowledge of the organization alone is not enough for the optimal solution of industrial hygiene problems. The industrial hygienist must have the necessary professional education and expertise.

The capable industrial hygienist who has made the in-house adjustment to the organization's problems should have the versatility and capability to deal with any industrial hygiene problem that may arise. In the development of a new product, for example, he or she should be able to meet with research and development personnel and find out what information is needed. This might include toxicological information, labeling requirements, assistance to customers, and any special engineering control requirements as the research effort progresses through pilot state to commercial production.

With the assistance of a qualified epidemiologist, the industrial hygienist can study an existing (or even a suspected) environmental health problem through epidemiological and biostatistical approaches, in addition to the usual sampling and measuring procedures. The industrial hygienist should know where to go (for example, personnel, purchasing, or process engineering) for the information he or she

needs to investigate and solve a problem. If the industrial hygienist knows of another organization engaged in making similar products, he or she can exchange information with its industrial hygienist and may be able to exchange visits.

Industrial hygienists must work well with other professionals, such as physicians, nurses, safety engineers, toxicologists, health physicists, and others, in and out of the organization. They must also communicate and work very closely with employees. Employees have insights into potential health hazards in their work area that only those working with the processes every day can possess. They are a primary source of information and suggestions for the industrial hygienist.

Industrial Hygiene Manager

In an industry setting, the industrial hygiene manager supervises the technical and support staff in a health and safety department; prepares budgets and plans; is familiar with government agencies related to the operation; relates industrial hygiene operations to research and development, production, environmental, and other departments or functions; and prepares appropriate reports. He or she may be called on to assist the corporate legal department when regulatory and worker compensation issues arise. The industrial hygiene manager should be certified by the ABIH (see the description of this organization in the Addendum to this chapter).

Many aspects of industrial hygiene expertise are unique. It makes sense for the industrial hygienist to extend his or her capabilities and sphere of activity by delegating responsibilities to others. This calls for supervisory and planning skills. The industrial hygienist must be able not only to plan, direct, and supervise technicians and assistants, but also to plan, program, and budget the activities of the department and staff. As a manager, he or she must establish priorities and initiate appropriate corrective action. The industrial hygienist and the industrial hygiene manager must both be effective communicators. Many aspects of their work involve formal or impromptu training of employees, managers, and visitors to a facility. These professionals may also be called on to discuss an organization's health and safety goals and accomplishments with the media and other members of the public, and they must be articulate, knowledgeable, and able to convey technical information in nontechnical language.

In the last decade many companies have collapsed the duties of safety and industrial hygiene manager into one function or position, and have sometimes added responsibility for other functions such as environmental safety, facility security or risk management. This has sometimes required that routine activities such as exposure monitoring be delegated to personnel at lower levels. Such facilities may also have concurrently reduced the size of their safety/health/environmental departments, and instead may rely on outside contractors to provide the personnel and skills necessary for various industrial hygiene projects. Other facilities may put the burden of more technical exposure assessment back on the "manager," who again becomes, in some cases, a "hands-on hygienist," without the assistance of a staff to support him or her with numerous responsibilities. Because they have the most experience and expertise, managers in these situations are likely to be called on to do the most complicated and advanced industrial hygiene tasks. Such a high degree of responsibility reinforces the need for a recognized level of competence in industrial hygiene personnel, which is provided by the certification mechanism.

Certified Industrial Hygienist (CIH)

The designation of certified industrial hygienist by the ABIH indicates that a person has received special education and has lengthy experience and proven professional ability in the comprehensive practice or the chemical practice of industrial hygiene.

The employer, employees, and the public have a right to be reasonably assured that the person to whom their lives are entrusted is professionally capable. One route by which such protection is provided is through licensing, usually by a government agency, a peer review arrangement or both. Certification by the American Board of Industrial Hygiene (ABIH) provides this assurance. Additionally, industrial hygienists in a number of states have worked to develop various forms of licensing to ensure that only well qualified industrial hygienists are allowed to promote themselves as such.

For certification by the ABIH, an individual must meet rigorous standards of education and experience before proving, by written examination, competency in either the comprehensive practice of industrial hygiene or the chemical practice (see Addendum). Diplomates of the ABIH are eligible for membership in the American Academy of Industrial Hygiene.

Certification provides some assurance that this individual possesses a high level of professional competence. The certified industrial hygienist is the person most likely to direct an industrial hygiene program capably, to work with other professions and government agencies, and to provide the vision and leadership of an industrial hygiene program to keep occupational hazards at a minimum in a rapidly changing technology and society. At the time of this writing, there are about 6400 active CIHs.

All CIHs must actively work to maintain their certification by earning a specified number of certification maintenance points during a five-year cycle. These points are awarded for working as an industrial hygienist; participating in professional associations; attending approved meetings, seminars and short courses; participating on technical committees; publishing in peer-reviewed journals; teaching, when not part of their primary practice; and other ABIH-approved activities.

The American Board of Industrial Hygiene has introduced a new industrial hygiene certification in 2001 for those professionals who have industrial hygiene responsibilities, but do not qualify for the Certified Industrial Hygienist (CIH) designation. This will include environmental health

science (EHS) professionals who do not practice industrial hygiene a majority of their total work time as well as those who primarily function in a single industrial hygiene area such as air pollution, ergonomics, or health physics, and who do not meet the CIH requirement for broad-scope IH work experience. This certification will be titled the Certified Associate Industrial Hygienist (CAIH).

The basic qualifications will include:

- a bachelor's degree with at least 30 semester hours of science and math
- industrial hygiene college or professional development courses covering fundamentals, measurements, controls and toxicology
- four years of post-bachelor, professional-level industrial hygiene experience (at least 25% IH activities)
- successful completion of a written exam

The certification will be designed to demonstrate competence in applying fundamental industrial hygiene knowledge and skills. (Consult ABIH for the most current rules.)

Of course, all of the previously described categories of ABIH certification—CIH, CAIH, IHIT, and OHST—are open to all industrial hygiene personnel, whether they are employed in industry, government, labor unions, educational institutions, or consulting, as long as they meet the qualifications. However, federally employed industrial hygienists also have their own unique training programs that reflect the structure and duties of their positions.

INDUSTRIAL HYGIENE, CIVIL SERVICE

For industrial hygiene trainees, assignments are selected and designed to orient the new employee into the field of industrial hygiene, to determine areas of interest and potential, to relieve experienced industrial hygienists of detailed and simple work, and to develop the trainee's knowledge and competence. Specific assignments are carried out under direct supervision of a qualified industrial hygienist, including recognition and evaluation of hazards, identification of controls, calibration of equipment, collection of samples, and initial preparation of reports. During inspections, the trainee observes specific safety items.

Under the general supervision of a senior industrial hygienist, the trainee begins to conduct more complex industrial hygiene inspections, including selection of sampling methods and locations, evaluation of controls and monitoring procedures, and preparation of reports. Completed work is reviewed for overall adequacy and conformance with policy and precedents. The industrial hygienist determines engineering feasibility, sets periods of abatement, interprets standards, and defends appeals under supervision of a senior industrial hygienist.

The senior industrial hygienist performs complete industrial hygiene inspections and prepares the final report. He or she determines engineering feasibility, sets periods of abatement, defends appeals, interprets standards, and provides offsite consultation. He or she receives general assignment of objectives and definition of policy from supervisors. The senior industrial hygienist differs from the industrial hygienist in that he or she receives more complex assignments and may act in place of the industrial hygiene supervisor when the supervisor is absent.

Training Plan for Entry-Level OSHA Industrial Hygienists

On July 7, 1992, Assistant Secretary for Occupational Safety and Health Dorothy Y. Strunk issued an OSHA instruction specifying a revised training program for OSHA compliance personnel. The instruction provided policies and guidelines for the implementation of technical training programs and described a federal program change that also affects state OSHA programs. This revised training program applies to both newly hired and experienced compliance personnel and is still in effect.

The training program is designed to provide a series of training courses supported by on-the-job training and self-instructional activities to ensure that compliance personnel are able to apply technical information and skills to their work; however, the elements of the training program are not meant to be prerequisites for advancement.

Objectives. On completion of the developmental training program, the compliance safety and health officer (CSHO) will have the following skills:

- A working knowledge of the fundamentals of hazard recognition, evaluation, and control
- Adequate knowledge of the implementation of engineering controls, abatement strategies, and the interpretation of data
- A reasonable comprehension of basic industrial processes and the ability to make quantitative observations and measurements
- Field experience in the proper calibration and use of measuring instruments
- The ability to perform solo or team inspections in most types of industries
- Knowledge of regulations and laws that involve safety and health in the workplace
- The ability to present inspection data in a legal proceeding efficiently
- The ability to make a referral to other appropriate industrial hygienists or safety officers

ORGANIZATIONAL TRAINING RESPONSIBILITIES

The mission of the Occupational Safety and Health Administration (OSHA) Office of Training and Education is to provide a program to educate and train employers and employees in the recognition, avoidance, and prevention of unsafe and unhealthful working conditions and to improve the skill and knowledge levels of personnel engaged in work relating to the Occupational Safety and Health Act of 1970.

The Office of Training and Education consists of four components:

- ➢ *Division of Training and Educational Programs.* This division is responsible for planning agency technical training programs and for managing the Susan B. Harwood grants.
- ➢ *Division of Training and Educational Development.* This division is responsible for developing and updating safety and health training programs and related materials.
- ➢ *Division of Administration and Training Information.* This division is responsible for providing administrative and informational programs for the Office of Training and Education.
- ➢ *OSHA Training Institute.* The Training Institute is responsible for the delivery of training to the populations served by the agency.

Specific responsibilities of the OSHA Training Institute include the following:

- ➢ Conducting programs of instruction for federal and state compliance officers, state consultants, other federal agency personnel and private sector employers, employees, and their representatives
- ➢ Participating in the development of course outlines, detailed lesson plans, and other educational aids necessary to carry out training programs

Each of OSHA's ten regions has a regional training officer or technician, who assists the regional administrator in coordinating the management of all regionwide training programs. This individual serves as the focal point in the regional office, ensuring the successful implementation of the training program for regional compliance personnel. Specifically, the regional training officer or technician assists in providing resource material and current training information to area directors and supervisors concerning the implementation of the objectives of the training program and evaluates and monitors all records of training.

In OSHA area offices, the area director has overall responsibility for ensuring and implementing the development and training of newly hired and experienced CSHOs under his or her supervision. The supervisor, however, serves as the main focal point in the area office for ensuring training. The supervisor provides and coordinates instruction, assistance, and guidance to the CSHOs in order to meet the training program objectives. Reviewing and maintaining progress records for each CSHO and assigning senior CSHOs to assist in on-the-job training of new hires is also performed by the supervisor.

The program itself provides a well-articulated progression of training requirements for newly hired personnel. The elements include formal training at the OSHA Training Institute and informal training such as self-study and on-the-job training (OJT). Figure 23–1 illustrates the developmental training plan for new hires.

INFORMATIONAL PROGRAM

The developmental training plan begins with the study of an informational package of materials developed jointly by the national office, the regional office, and the Office of Training and Education. Contents include information on the U.S. Department of Labor; an introduction, history, and purpose statement; the structures of regional and area offices, procedures, and libraries; common OSHA acronyms; individual training development programs; and such handout items as organizational charts, the *Field Operations Manual* (FOM), standards, directives, personal protective equipment, and instruments.

SELF-STUDY PROGRAM

Before attending the initial compliance course at the OSHA Training Institute, each CSHO is required to complete three self-study programs on the OSHAct, Chapter III of the *Field Inspection Reference Manual* (FIRM), and Integrated Management Information Systems (IMIS) forms 1, 1A, 1B, and 1B-IH. During these self-study assignments, the CSHO becomes familiar with the basic OSHAct requirements; studies basic inspection procedures in Chapter III of the FOM, and becomes familiar with the most commonly used forms.

OSHA TRAINING INSTITUTE

After completing the basic self-study prerequisites, each CSHO is required to complete coursework in one of three tracks: safety, health, or construction.

Initial compliance course. This provides new CSHOs with an understanding of occupational safety and health programs, and a working knowledge of the FOM and OSHA policies.

Technical courses in safety, health, or construction. These courses provide new-hire CSHOs with a thorough introduction to the organization and content of the standards and to hazard recognition and documentation.

Inspection techniques and legal aspects. This provides new CSHOs with an understanding of basic communication skills, formal requirements and processes of the legal system, and investigative techniques related to OSHA compliance activity.

Additional technical courses (at least two courses required). These provide the CSHO with technical knowledge, skills, and information on hazard recognition as related to OSHA requirements. The specific courses are determined by the supervisor based on individual need. Figure 23–1 lists the technical courses in each track.

Crossover training. Because CSHOs must be familiar with general concepts of safety and health, each CSHO is required to complete crossover training during the developmental period. CSHOs on the safety or construction track are encouraged to attend the introduction to health course; industrial hygienists are encouraged to attend the introduction to safety course.

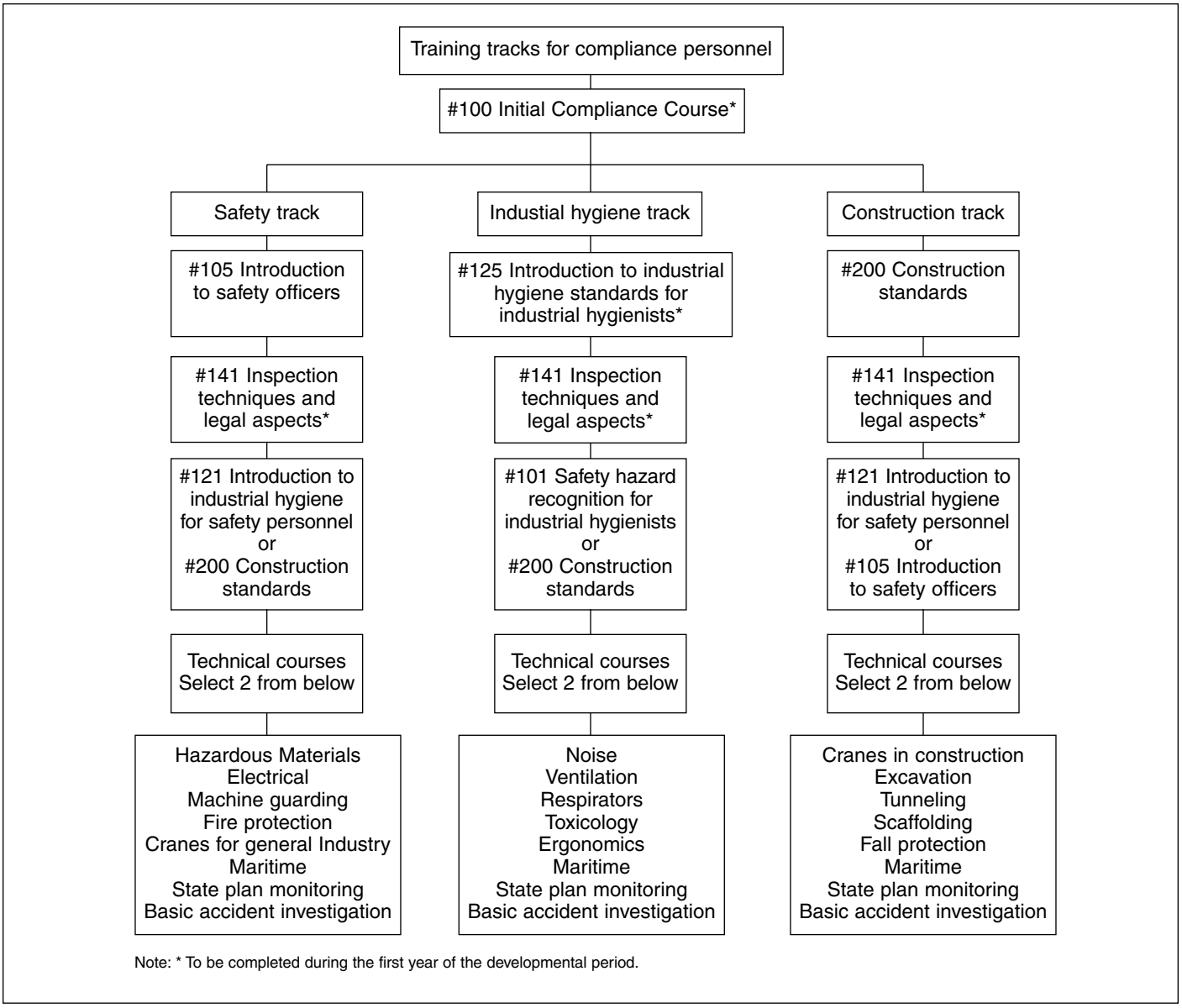

Figure 23–1. The OSHA training tracks for compliance personnel. (Source: OSHA Instruction TED 1.12A, Office of Training and Education.)

CONTINUING MAINTENANCE OF SKILLS AND KNOWLEDGE

Once the training period is completed, CSHOs typically require additional training to keep themselves current in the safety and health field. At a minimum, each CSHO is required to attend a technical course once every 3 years at the OSHA Training Institute. If an institute course has changed significantly during the years, the CSHO is permitted to repeat the course.

CSHOs are also encouraged to pursue other training opportunities available both within the Department of Labor and elsewhere.

PERSONNEL NEEDS AND PROBLEMS

The American Industrial Hygiene Association reports a national membership of 12,300 in late 2001, with 76 local sections.. If local section AIHA members who are not also national members are included, the figure rises to approximately 15,000.

The American Conference of Governmental Industrial Hygienists (ACGIH) has a membership of approximately 5,000 industrial hygienists from 52 countries. Many hygienists belong to both organizations, limiting the data's usefulness as an estimate of the total number of professional industrial hygienists.

In 1975, OSHA, using 1973 NIOSH data, reported a national census of only 500 industrial hygienists, but 15,000 occupational safety and health specialists. The OSHA estimate indicated a then-current need for 5,500 industrial hygienists and 24,000 safety and health specialists. At that time, OSHA also predicted the need for 11,900 industrial hygienists and 62,300 occupational safety and health specialists by 1985.

Cycles of growth and contraction in industry and government will undoubtedly continue to affect the demand for industrial hygienists well into the 21st century. In the 1980s, expansion of the need for hygienists came in nontraditional areas such as environmental remediation, indoor air quality, and a number of areas that many see as temporary trends; asbestos management and remediation projects are prime examples. In the 1990s, however, downsizing by many corporations resulted in industrial hygienists often functioning as safety and environmental or even risk-management professionals, or delegating responsibilities such as safety training to less trained and credentialed personnel. Some industrial hygienists whose corporate jobs were eliminated now serve as private consultants to a variety of clients, including the corporations they left. Whereas 42 percent of AIHA's members are in private industry, consultants (in firms or self-employed) make up about 24–25 percent of the membership, up from about 10 percent in 1984.

Additionally, if a contraction of government agencies occurs because of a changing political climate, this may mute the demand for industrial hygienists in both industry and government. However, the 1990s also saw a movement by large industry, particularly multinational or "global" employers, to adopt national and international voluntary standards, such as those developed through the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO). ISO 14000, which deals with an organization's management of its relationship to the environment, is such an example. Industrial hygienists clearly have roles to play in developing and helping implement the goals and objectives of these programs to ensure that an organization truly enhances worker safety as it conforms to these voluntary standards.

The absolute need for individuals trained in the prevention of disease and preservation of health and safety will not change. Eventually, data such as worker compensation costs and illness and injury rates will reveal the need for prevention rather than repair of injury.

Education and Training Programs

The education and training programs for industrial hygiene include professional school training, graduate curricula, and continuing education (short courses). Professional school curricula in industrial hygiene generally culminate in a Master of Science or a Master of Public Health degree.

Educational Resource Centers

NIOSH's findings of shortages of trained occupational safety and health graduates were cited in successful efforts to expand training grants programs. One part of this expansion was the introduction of multidisciplinary educational resource centers (ERCs). The other part was growth of single-discipline training grants.

Congress authorized creation of up to 20 Educational Resource Centers for occupational safety and health in 1976. Funding increased from $2.9 million in 1977 to $12.9 million in 1980, and in 2000 the ERCs now number 15. In 1998 the name of these facilities was changed to Education and Research Centers. These centers provide continuing education to occupational health and safety professionals; combine medical, industrial hygiene, safety, and nursing training so that graduates are better able to work effectively in complex and diverse conditions; conduct research; and conduct regional consultation services. All ERCs are located in universities. The centers are distributed as widely as possible to give regional representation and to meet training needs for all areas of the nation.

The ERCs should not be confused with the OSHA Training Institute education centers, a program in which designated nonprofit organizations offer the most frequently requested OSHA Training Institute courses for the private sector and other Federal agency personnel. There are currently 12 of these OSHA education centers around the U.S.

Professional Schooling

A program of study leading to a professional degree in industrial hygiene should start with two years of basic arts and sciences, two years of derivative sciences and advanced subjects, and two years of professional courses. Such an advanced degree might appropriately be designated Doctor of Occupational Health, Doctor of Public Health, Doctor of Science, or Doctor of Engineering. Regardless of its name, however, it should be clearly understood that such a degree is a professional scholar's degree.

Graduate Curricula

Graduate study programs have generally been developed to provide in-depth knowledge of a particular subject area and to develop scholarly research capabilities. The Accrediting Board of Engineering and Technology (ABET) has accredited master's level programs in industrial hygiene since 1985 and currently also accredits baccalaureate level programs. In early 2000 there are 21 accredited master's level programs and 5 accredited baccalaureate level programs. ABET considers industrial hygiene (as well as safety, industrial management, or quality management) to be engineering related fields. The American Academy of Industrial Hygiene has been the lead organization responsible for submitting program criteria for industrial hygiene baccalaureate and master's programs to ABET. In the past these criteria stated specific numbers and types of semester hours of credit that degree candidates needed to complete the degree program. For example, a baccalaureate degree program required 63 or more semester hours of college-level mathematics, including technological courses and a minimum of 21 semester hours in communications, humanities, and social sciences. In the late 1990s ABET's approach changed to one that asked organizations to state their criteria in terms of outcome measures. While these are still undergoing final review, the proposed new criteria for baccalaureate and master's level

programs in industrial hygiene are a combination of general criteria expected in all types of engineering related programs, and specific criteria for industrial hygiene programs.

The general criteria for baccalaureate level programs require the institution to evaluate and monitor students to determine if the program is meeting its objectives and that students are meeting program requirements.

Such programs must have detailed published educational objectives and curriculum and processes that ensure the achievement of these objectives as well as a system of ongoing evaluation that demonstrates achievement of these objectives and uses the results to improve the effectiveness of the program.

Programs must be able to demonstrate that graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering-related applied sciences
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to formulate or design a system, process or program to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify and solve engineering-related problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of solutions in a global and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern scientific and technical tools necessary for professional practice.

Each program must have an assessment process with documented results. Evidence must be given that the results are applied to the further development and improvement of the program. The assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program, including those listed above, are being measured.

The professional component requirements specify subject areas appropriate to engineering-related programs, but do not prescribe specific courses. The program's faculty must assure that the engineering-related curriculum devotes adequate attention and time to each component, consistent with the objectives of the program and institution. Students must be prepared for engineering-related practice through the curriculum culminating in comprehensive projects or experiences based on the cumulative knowledge and skills acquired in earlier coursework.

Faculty

Rather than specifying specific numbers of faculty as it did in the past ABET now will require that

> *the faculty must be of sufficient number as determined by student enrollment and the expected outcome competencies of the program. The faculty must have sufficient qualifications and must ensure the proper guidance of the program and its evaluation and development. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, applicable experience, teaching performance, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and applicable certifications, registrations, or licensures.*

The proposed criteria also state requirements for facilities, institutional support and financial resources. Criteria specific to industrial hygiene programs require that they

> *must demonstrate that graduates have necessary knowledge, skills, and attitudes to competently and ethically implement and practice applicable scientific, technical, and regulatory aspects of Industrial Hygiene. Graduates must be prepared to anticipate, recognize, evaluate and control exposures of workers and others to physical, chemical, biological, ergonomic and psychosocial factors, agents and/or stressors that can potentially cause related diseases and/or dysfunctions.*

ABET also specifies a list of required outcome measures such as being able to describe qualitative and quantitative aspects of generation of agents, factors, and stressors. The ABET criteria state that

> *Master's level program candidates must hold an earned baccalaureate that prepares them to apply the basic principles of college-level mathematics, inorganic and organic chemistry, physics, and biology.*
>
> *Criteria for master's-level programs require the following additions beyond the baccalaureate level: (i) minimum of one year of study beyond the basic-level, consisting of courses with increased depth and rigor; (ii) an applied science project or research activity resulting in a report that demonstrates both mastery of the subject matter and a high level of professional and public communication skills; (iii) an adequate foundation in statistics, applied sciences, and/or related professional practice; and, (iv) advanced qualitative and quantitative problem-solving skills.*

Continuing Education

A wide variety of opportunities exist for industrial hygienists who want to remain technically current, receive training in previously unfamiliar aspects of industrial hygiene, pursue academic coursework leading to a more advanced degree, or earn certification maintenance points in order to maintain CIH certification.

A number of universities offer coursework leading to degrees. Also available at such universities are usually short courses (a few days or weeks long) on specific industrial hygiene topics. Summer institutes (1–4 weeks long) concentrating on a particular area of industrial hygiene are another continuing education opportunity.

NIOSH publishes an annual catalogue of all such training courses nationwide at universities that are funded as NIOSH ERCs. Most ERCs contain an industrial hygiene component that includes coursework leading to academic degrees and short courses. The catalogue can be obtained through the NIOSH publications dissemination office or at its website. Between 1993 and 1998 NIOSH provided continuing education for 184,000 professionals. A number of other not-for-profit and for-profit training organizations provide short courses in industrial hygiene and related topics. These include the National Safety Council and professional industrial hygiene and safety societies as well as consulting firms. The computerization of nearly all U.S. workplaces has engendered the development of a wide range of self-paced educational activities, including programs that can be delivered by CD-ROM or over the Internet. Large numbers of web sites now address safety, industrial hygiene, and environmental issues. There are also a variety of list-servers on environmental and occupational health that deliver up-to-date information to a computer subscription list. There are on-line discussion groups and bulletin boards; for example the ACGIH sponsors "topic walls" that allow users to participate in posting questions and answers on industrial hygiene topics, broken into the categories of Recognition, Evaluation, and Control. New technologies also allow courses and seminars to be delivered over the web or via video conference.

SUMMARY

The need to control exposures to a rapidly rising number of chemicals and hazardous agents and to comply with and enforce governmental regulations and voluntary guidelines has brought about greater demand for industrial hygienists. This demand exists in private industry, labor unions, government, and academic organizations.

Individuals practicing industrial hygiene routinely work as a team; thus, the physician, the nurse, the safety professional, and the industrial hygienist are quite accustomed to working together. Other professions are included as needed; these include toxicologists, health physicists, epidemiologists, statisticians, professional trainers, and educators. A team approach, using the knowledge and skills of all these professionals, increases the effectiveness of programs to prevent occupational disease and injuries and helps to anticipate future requirements.

The need continues for industrial hygienists to interpret the findings of environmental investigations and to design and implement control measures. The industrial hygienist must, therefore, have the generalist's grasp of varied disciplines in order to interact with divergent groups in developing and maintaining the most effective program.

Educational requirements for industrial hygienists will continue to expand with the increasing need to monitor and control hazardous agents and to comply with more stringent government regulations and voluntary guidelines and standards such as those promulgated by the American National Standards Institute and ACGIH. The training program for OSHA CSHOs was also discussed.

Personnel from three professional specialties—industrial hygiene, safety, and environmental health—will be working even more closely together in the future, their responsibilities overlapping in many instances. The separation between these professions has become increasingly blurred, and melding may eventually lead to the creation of a single profession whose scope is made up of what is currently recognized today as industrial hygiene and safety.

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ADDENDUM: PROFESSIONAL SOCIETIES AND COURSES OF INTEREST TO INDUSTRIAL HYGIENISTS

American Industrial Hygiene Association

The AIHA is a nonprofit professional society for people practicing industrial hygiene in industry, government, labor, academic institutions, and independent organizations. In late 2001, AIHA had a membership of 12,300 members, plus 76 local sections drawn from the United States, Canada, and 43 other countries.

The AIHA was established in 1939 by a group of industrial hygienists to provide an association devoted exclusively to industrial hygiene. AIHA is a national society of professionals engaged in protecting the health and well-being of workers and the general public through the scientific application of knowledge concerning chemical, engineering, physical, biological, or medical principles to minimize environmental stress and to prevent occupational disease.

The AIHA promotes the recognition, evaluation, and control of environmental stresses arising in the workplace and encourages increased knowledge of occupational and environmental health by bringing together specialists in this field. The American Industrial Hygiene Conference and Exposition, cosponsored by AIHA, draws more than 10,000 industrial hygiene professionals each May or June.

AIHA Membership Qualifications and Types

Full membership is for individuals who have worked primarily in industrial hygiene-related activities for at least three years and meet other educational requirements. Full members may serve on committees, vote, and be elected to the AIHA Board of Directors.

Diplomate members are those individuals who meet the requirements for board certification in their respective discipline as recognized by AIHA. AIHA members in good standing who meet these criteria will belong to the respective diplomate division of AIHA. They will have the same organizational rights as full members.

Associate membership is for individuals who have less than three years of experience in the industrial hygiene field. An associate member may serve on committees and vote, but may not be elected to the AIHA Board of Directors.

Any person who interacts with occupational and environmental health professionals may become an affiliate member of AIHA. An affiliate member may serve on committees, but may not vote or be elected to the AIHA Board of Directors.

A full-time college student may become a student member of AIHA. A student member may not serve on committees, vote, or hold office. Student members can receive the *AIHA Journal* at a special discounted price.

Organizational membership is open to organizations having an interest in the industrial hygiene profession.

Local Section Membership

Any person with a professional interest in industrial hygiene may apply for membership in an AIHA local section. Application for membership in a local section should be made to the local section.

Address: American Industrial Hygiene Association, 2700 Prosperity Ave., Suite 250, Fairfax, VA 22031, (703) 847-8888, www.aiha.org.

American Board of Industrial Hygiene

The American Board of Industrial Hygiene (ABIH) was established to improve the practice and educational standards of the profession of industrial hygiene. To this end, the ABIH engages in the following activities:

- ➢ To receive and process applications for examinations and to evaluate the education and experience qualifications of the applicants for such examinations
- ➢ To grant and to issue (to qualified people who pass the board's examinations) certificates acknowledging their competence in industrial hygiene and to revoke certificates so granted or issued for cause
- ➢ To provide for maintenance of certification by requiring evidence of continued professional qualifications by certificate holders in the comprehensive or chemical practice of industrial hygiene
- ➢ To maintain a record of certificate holders
- ➢ To furnish to the public, and to interested people or organizations, a roster of certificate holders having special training, knowledge, and competence in industrial hygiene

The American Board of Industrial Hygiene issues three categories of certificates. The first certifies that the individual has the required education, experience, and professional ability in the comprehensive practice or chemical practice of industrial hygiene (CIH). The second category is the industrial hygienist in training (IHIT) certification. This designation has been eliminated. Current IHITs have six years to test for CIH status. The third category, the occupational health and safety technologist (OHST) designation, is a joint certification with the Board of Certified Safety Professionals (BCSP). The OHST examination procedure is administered by the CCHEST (see Bibliography).

As previously discussed, ABIH introduced a new certification, the Certified Associate Industrial Hygienist, in 2001. Each applicant for the traditional Certification in industrial hygiene until recently has had to pass a two-part

examination. In 2001 the first, or Core, examination was eliminated. But the more visible change (beginning spring of 2001) was the elimination of the Core Exam (and IHIT program). The ABIH decided that two full-day examinations were not necessary to identify CIH level practitioners. A single exam has been constructed to test both the general knowledge/information aspect previously tested by the Core Exam and the more applied/experiential aspects of the Comprehensive Exam.

Also, the existing specialty certification in Chemical Practice and the Indoor Environmental Quality (IEQ) subspecialty certification program were both suspended in 2000.

CERTIFICATION MAINTENANCE

The ABIH also administers a certification maintenance program for CIHs. The purpose of this program is to ensure that CIHs continue to develop and enhance their professional industrial hygiene skills for the duration of their careers. The certificate is granted for a period of six years, after which time it expires unless renewed. Certificate holders must provide evidence to the board of their continued professional qualifications in order to renew the certificate. Activities that are accepted as evidence include continuing professional industrial hygiene practice; membership in an approved professional society (other than the American Academy of Industrial Hygiene); attendance at approved meetings, seminars, and short courses; participation in technical committees; publishing in peer-reviewed journals; teaching that is not part of the diplomate's primary practice; approved extracurricular professional activities; and reexamination or examination for an additional certification. Points for the approved activities are awarded and publicized by the board, as is a schedule for renewal of certificates.

Besides being entitled to use the CIH designation, people certified in either comprehensive practice or chemical practice become members of the American Academy of Industrial Hygiene and their names are published in the annual roster of the academy. The names of IHITs are also published in the academy roster.

Address: American Board of Industrial Hygiene, 6015 West St. Joseph, Suite 102, Lansing, Michigan 48917-3980, (517) 321-2638, www.abih.org.

American Academy of Industrial Hygiene

The American Academy of Industrial Hygiene (AAIH) has been a professional association of practicing industrial hygienists who have participated successfully in the certification program administered by the American Board of Industrial Hygiene (ABIH). Completion of this program demonstrates the highest degree of proficiency in the practice of industrial hygiene.

In 1957, the American Industrial Hygiene Association (AIHA) set out to establish a certification program for qualified industrial hygienists. The American Conference of Governmental Industrial Hygienists joined the effort in 1958. The ABIH was incorporated as an independent organization to develop and administer the certification program. Six members from each sponsoring organization made up the first board; its first annual meeting was held in 1960. In 1966, the diplomates activated the AAIH as a professional organization. In 1999 AIHA and AAIH voted to merge the Academy into AIHA; the AAIH became the Academy of Industrial Hygiene.

The purpose of the AIH is to establish high standards of professional conduct and professionalism among those practicing in the field of industrial hygiene. AIH seeks to promote recognition of the need for high-quality industrial hygiene practice to ensure healthful work conditions in the occupations and industries its members serve.

Activities include establishment of a code of ethics to serve as a guide for professional conduct by industrial hygienists; promotion of the recognition of industrial hygiene as a profession by individuals, employers, and regulatory agencies; advancement of board certification as a basic qualification for employment as an industrial hygienist in both public and private organizations; accreditation of academic programs in industrial hygiene in cooperation with the Accreditation Board of Engineering and Technology; and recruitment of students into academic programs and training through initial education and continuing education for practicing industrial hygienists.

The AIH sponsors the Professional Conference on Industrial Hygiene to provide a forum for exploring professional issues. Continuing education opportunities also are provided. The conference is aimed primarily at issues encountered by the more experienced industrial hygienist but is not restricted to members of AIH.

American Conference of Governmental Industrial Hygienists

The American Conference of Governmental Industrial Hygienists (ACGIH) was organized in 1938 by a group of government industrial hygienists who desired a medium for the free exchange of ideas and experiences and the promotion of standards and techniques in occupational and environmental hygiene.

As an organization devoted to the development of administrative and technical aspects of worker health protection, the ACGIH has contributed substantially to the development and improvement of official occupational health services to industry and labor. ACGIH endeavors to provide opportunities, information, and other resources needed by those who protect worker health and safety. Technical committees, publications, symposia, journals, and other programs work toward this goal. The committees on industrial ventilation and Threshold Limit Values® are recognized throughout the world for their expertise and contributions to industrial hygiene. The ACGIH sets TLVs® and annually updates these values.

The mission of the ACGIH is to be an indispensable resource for industrial hygienists and related professionals

worldwide. Its purposes are to promote excellence in environmental and occupational health; to provide technical information of the highest quality; to benefit the occupational health and well-being of people worldwide; and to serve the membership and continually improve the organization, including its financial and human resources. It operates a Publications Clearinghouse and Resource Information Center and provides a variety of products and services members' needs, including the yearly revision of *Threshold Limit Values® for Chemical Substances and Physical Agents and Biological Exposure Indices.®* This booklet is an indispensable resource that contains quantitative exposure guidelines industrial hygienists use to compare to air and biological sampling results.

ACGIH MEMBERSHIP

ACGIH was originally formed as an organization of industrial hygienists who worked in government. It has recently expanded its scope to offer membership to a broader spectrum of practitioners. Today, anyone who is engaged in the practice of industrial hygiene or occupational and environmental health and safety is eligible for one of six categories of membership. Consult ACGIH for the most current rules.

A *full member* is an industrial hygienist or occupational health, environmental health, or safety professional whose full-time, primary employment is with a governmental agency or an educational institution and who is engaged in health or safety services, standard setting, enforcement, research, or education. Full members are accorded full voting privileges and can serve as officers or members-at-large of the Board of Directors as well as on any appointive committee.

An *associate member* is a person professionally employed in a full-time activity closely allied to industrial hygiene, occupational health, environmental health, or safety who is either an employee of a government agency or an educational institution, or who works more than 50 percent of his or her time on a government contract at a government facility. An associate member may also be a person with at least 10 years of membership in the full or technical category who has retired or is eligible for retirement benefits from a government agency or educational institution but who is employed in the field at least 25 percent of his or her time by a government agency or educational institution. Associate members may vote on all conference matters and may serve as a member-at-large on the Board of Directors or as a member of an appointive committee.

A *technical member* is a technician employed in a full-time activity by a government agency or an educational institution in industrial hygiene, occupational health, environmental health, or safety. A technical member may also be a person who works more than 50 percent of his or her time on a government contract at a government facility that is engaged in such services. Technical members have the same voting and service privileges as associate members.

Student members are people officially enrolled in a full-time course of study directly related to industrial hygiene, occupational health, environmental health, or safety. Evidence of academic enrollment must include one of the following: current transcript, current class schedule, or a letter of reference from an academic advisor (on university or college letterhead) indicating that the applicant is a full-time student. Students may not vote or hold elected office but may serve on appointive committees.

An *emeritus member* is a full, associate, or technical member who has retired from the practice of industrial hygiene, occupational health, environmental health, or safety and who has been a member of the conference for a minimum of 10 consecutive years. Retirement is defined as employment less than 25 percent of full-time. These members retain the rights and privileges of the category from which they qualified for this status.

Affiliate members are people engaged in health or safety services who are not currently eligible for another category of membership. They may not vote on conference matters or hold elected office but they may serve as consultants on appointive committees.

Address: ACGIH, Kemper Meadow Center, 1330 Kemper Meadow Drive, Cincinnati, OH 45240.

American Public Health Association

The American Public Health Association (APHA), established in 1872, is 50,000 strong in its collective membership, which represents all the disciplines and specialties in the public health spectrum. The APHA is devoted to the protection and promotion of public health. It achieves this goal in several ways:

- ➢ Sets standards for alleviating health problems
- ➢ Initiates projects designed for improving health, both nationally and internationally
- ➢ Researches health problems and offers possible solutions based on that research
- ➢ Launches public awareness campaigns about special health dangers
- ➢ Publishes materials reflecting the latest findings and developments in public health

The APHA has 35 special sections, including an occupational health and safety section that includes occupational health physicians and nurses, industrial hygienists, and other allied occupational health professionals. Each APHA section has its own professional meetings to provide a forum for the exchange of ideas.

APHA MEMBERSHIP

Six types of membership are available:

- ➢ Regular membership is available to all health professionals.
- ➢ Contributing membership provides additional association benefits.

Special memberships include the following:

- ➢ Student/trainee: people enrolled full-time in a college or university or occupied in a formal training program in preparation for entry into a health career

- ➢ Retired: APHA members who have retired from active public health practice and no longer derive significant income from professional health-related activities
- ➢ Consumer: people who do not derive income from health-related activities
- ➢ Special health workers: people employed in community health whose annual salary is less than $30,000 (or its equivalent for foreign nationals)

Address: American Public Health Association, 800 I Street NW, Washington, DC, 20001-3710, (202) 777-APHA, Website: www.apha.org

Chapter
24

The Safety Professional

by Peter B. Rice, CIH, CSP

This chapter deals with the role of the safety professional in an effective occupational safety and health program. The duties and functions of safety professionals and how they work with other professionals are briefly discussed, as well as several ways the safety professional can contribute to the success of an occupational safety and health program. As total safety is multidisciplinary it is critical that the industrial hygienist become familiar with the roles and function of the safety professional.

SCOPE AND FUNCTIONS OF THE SAFETY PROFESSIONAL

Safety is a multidisciplinary profession, drawing its professionals from many different fields such as safety management, education, engineering, psychology, medicine, biophysics, chemistry, and labor. Safety professionals are employed in nearly every industry and government sector. Interestingly, many professionals in the field did not initially choose safety as a career, but instead became interested in accident prevention and loss prevention while working in other disciplines. Many have made the change to the safety profession after recognizing the fact that a well-defined safety program promotes management's objective of producing high-quality products at the lowest cost.

The safety profession today is a sophisticated discipline combining engineering, chemistry, biology, behavioral psychology, and a knowledge about such topics as systems safety analysis, human factors engineering, biomechanics, and product safety (Figure 24–1, 24–2). In addition, the safety professional must possess a thorough knowledge of a facility's equipment, property, manufacturing processes, and employees. In many facilities the safety professional must be able to work with employees with varying linguistic and cultural backgrounds. The safety professional must display tact,

SCOPE OF A SAFETY PROFESSIONAL

To perform their professional functions, safety professionals must have education, training and experience in a common body of knowledge. Safety professionals need to have a fundamental knowledge of physics, chemistry, biology, physiology, statistics, mathematics, computer science, engineering mechanics, industrial processes, business, communication and psychology. Professional safety studies include industrial hygiene and toxicology, design of engineering hazard controls, fire protection, ergonomics, system and process safety, safety and health program management, accident investigation and analysis, product safety, construction safety, education and training methods, measurement of safety performance, human behavior, environmental safety and health, and safety, health and environmental laws, regulations and standards. Many safety professionals have backgrounds or advanced study in other disciplines, such as management and business administration, engineering, education, physical and social sciences and other fields. Others have advanced study in safety. This extends their expertise beyond the basics of the safety profession.

Because safety is an element in all human endeavors, safety professionals perform their functions in a variety of contexts in both public and private sectors, often employing specialized knowledge and skills. Typical settings are manufacturing, insurance, risk management, government, education, consulting, construction, healthcare, engineering and design, waste management, petroleum, facilities management, retail, transportation and utilities. Within these contexts, safety professionals must adapt their functions to fit the mission, operations and climate of their employer.

Not only must safety professionals acquire the knowledge and skills to perform their functions effectively in their employment context, through continuing education and training they stay current with new technologies, changes in laws and regulations, and changes in the workforce, workplace and world business, political and social climate.

As part of their positions, safety professionals must plan for and manage resources and funds related to their functions. They may be responsible for supervising a diverse staff of professionals.

By acquiring the knowledge and skills of the profession, developing the mind set and wisdom to act responsibly in the employment context, and keeping up with changes that affect the safety profession, the safety professional is able to perform required safety professional functions with confidence, competence and respected authority.

Figure 24–1. The scope of the professional safety position are reprinted with permission from the American Society of Safety Engineers website, www.asse.org.

diplomacy, persuasiveness, and persistence. In short, today's safety professional must wear many hats and play many roles.

The safety professional should serve as a counselor to the organization's chief executive. The safety professional must be able to enter the boardroom of an organization as an equal; to do this, he or she must understand the basic technology of the industry.

An increasing number of institutions of higher education offer degrees in safety engineering and/or safety management. Such courses are essential to the continuing development of safety and health professionals. There are more than 125 colleges and universities that offer degrees in safety management, occupational safety, environmental protection, or a related field. A list of these schools is available from the American Society of Safety Engineers at: ASSE, 1800 E. Oakton St., Des Plaines, IL 60018-2187.

In its broadest sense, occupational health has come to mean not only freedom from disease but from injury as well. Because of this, the safety professional has become more closely aligned with the industrial hygienist and the field of occupational medicine. It is rare to find a safety professional who does not also practice some traditional industrial hygiene or vice versa.

There is no question that accidents are painful and costly to the worker, the worker's family, and to society. (The term *accident* as used here is defined to mean any unexpected event that interrupts the work sequence or process and that may result in injury, illness, or property damage to the extent that it causes loss.) Accidents produce economic and social loss, impair individual and group productivity, cause inefficiency, upset employee morale and public image, and generally retard progress. Also, in today's world, an organization with a poor safety program often finds it difficult to compete.

Dedicated safety professionals continue to be accident prevention's most valuable asset. Their ranks have grown to the point where membership in the American Society of Safety Engineers (ASSE) is now more than 30,000. This organization, dedicated to the interests and professional development of safety engineers, has approximately 150 chapters in the United States and Canada, and it has members worldwide. There are many other qualified safety professionals in addition to the ASSE members, who, together with thousands of specialists and technicians, carry out a limited scope of activities within the occupational safety and health field.

FUNCTIONS OF A SAFETY PROFESSIONAL

The major areas relating to the protection of people, property and the environment are:

A. Anticipate, identify and evaluate hazardous conditions and practices.
B. Develop hazard control designs, methods, procedures and programs.
C. Implement, administer and advise others on hazard control programs.
D. Measure, audit and evaluate the effectiveness of hazard control programs.

A. Anticipate, identify and evaluate hazardous conditions and practices.

This function involves:

1. Developing methods for
   - ➢ Anticipating and predicting hazards from experience, historical data and other information sources.
   - ➢ Identifying and recognizing hazards in existing or future systems, equipment, products, software, facilities, processes, operations and procedures during their expected life.
   - ➢ Evaluating and assessing the probability and severity of loss events and accidents which may result from actual or potential hazards.
2. Applying these methods and conducting hazard analyses and interpreting results.
3. Reviewing, with the assistance of specialists where needed, entire systems, processes, and operations for failure modes, causes and effects of the entire system, process or operation and any subsystem or components due to:
   - ➢ System, subsystem, or component failures.
   - ➢ Human error.
   - ➢ Incomplete or faulty decision making, judgments or administrative actions.
   - ➢ Weaknesses in proposed or existing policies, directives, objectives or practices.
4. Reviewing, compiling, analyzing and interpreting data from accident and loss event reports and other sources regarding injuries, illnesses, property damage, environmental effects or public impacts to:
   - ➢ Identify causes, trends and relationships.
   - ➢ Ensure completeness, accuracy and validity of required information.
   - ➢ Evaluate the effectiveness of classification schemes and data collection methods.
   - ➢ Initiate investigations.
5. Providing advice and counsel about compliance with safety, health and evnironmental laws, codes, regulations and standards.
6. Conducting research studies of existing or potential safety and health problems and issues.
7. Determining the need for surveys and appraisals that help identify conditions or practices affecting safety and health, including those which require the services of specialists, such as physicians, health physicists, industrial hygienists, fire protection engineers, design and process engineers, ergonomists, risk managers, environmental professionals, psychologists and others.
8. Assessing environments, tasks and other elements to ensure that physiological and psychological capabilities, capacities and limits of humans are not exceeded.

B. Develop hazard control methods, procedures and programs.

This function involves:

1. Formulating and prescribing engineering or administrative controls, preferably before exposures, accidents, and loss events occur, to:
   - ➢ eliminate hazards and causes of exposures, accidents and loss events.
   - ➢ reduce the probability or severity of injuries, illnesses, losses or environmental damage from potential exposures, accidents, and loss events when hazards cannot be eliminated.
2. Developing methods which integrate safety performance into the goals, operations and productivity of organizations and their management and into systems, processes, operations or their components.
3. Developing safety, health and environmental policies, procedures, codes and standards for integration into operational policies of organizations, unit operations, purchasing and contracting.
4. Consulting with and advising individuals and participating on teams:
   - ➢ engaged in planning, design, development and installation or implementation of systems or programs involving hazard controls.
   - ➢ engaged in planning, design, development, fabrication, testing, packaging and distribution of products or services regarding safety requirements and application of safety principles which will maximize product safety.
5. Advising and assisting human resources specialists when applying hazard analysis results or dealing with the capabilities and limitations of personnel.
6. Staying current with technological developments, laws, regulations, standards, codes, products, methods and practices related to hazard controls.

(continues)

Figure 24–2. The functions of the professional safety position are reprinted with permission from the ASSE website (www.asse.org).

FUNCTIONS OF A SAFETY PROFESSIONAL (CONTINUED)

C. Implement, administer and advise others on hazard controls and hazard control programs.

This function involves:

1. Preparing reports which communicate valid and comprehensive recommendations for hazard controls which are based on analysis and interpretation of accident exposure, loss event and other data.
2. Using written and graphic materials, presentations and other communication media to recommend hazard controls and hazard control policies, procedures and programs to decision making personnel.
3. Directing or assisting in planning and developing educational and training materials or courses. Conducting or assisting with courses related to designs, policies, procedures and programs involoving hazard recognition and control.
4. Advising others about hazards, hazard controls, relative risk and related safety matters when they are communicating with the media, community and public.
5. Managing and implementing hazard controls and hazard control programs which are within the duties of the individual's professional safety position.

D. Measure, audit and evaluate the effectiveness of hazard controls and hazard control programs.

This function involves:

1. Establishing and implementing techniques, which involve risk analysis, cost, cost–benefit analysis, work sampling, loss rate and similar methodologies, for periodic and systematic evaluation of hazard control and hazard control program effectiveness.
2. Developing methods to evaluate the costs and effectiveness of hazard controls and programs and measure the contribution of components of systems, organization, processes and operations toward the overall effectiveness.
3. Providing results of evaluation assessments, including recommended adjustments and changes to hazard controls or hazard control programs, to individuals or organizations responsible for their management and implementation.
4. Directing, developing, or helping to develop management accountability and audit programs which assess safety performance of entire systems, organizations, processes and operations or their components and involve both deterrents and incentives.

Figure 24–2. More functions of the professional safety position are from the ASSE website (www.asse.org).

In 1968, the ASSE was instrumental in forming the Board of Certified Safety Professionals (BCSP). Its purpose is to provide the professional status of a Certified Safety Professional (CSP) to qualified safety professionals by certification after they have met strict education and experience requirements and passed an examination. As of late 2001, approximately 10,000 CSPs and approximately 1,200 Associate Safety Professionals (ASPs) had been certified by the BCSP. The ASP designation is awarded to those who pass the Safety Fundamentals Examination, the initial exam of the certification process, and indicates a recognition of a person's progress toward certification.

In 1985, the BCSP and the American Board of Industrial Hygiene (ABIH) began joint sponsorship of a certification program for occupational safety and health technologists (OHSTs). This designation is not intended for those who are certified industrial hygienists (CIHs) or CSPs, nor is it intended for those eligible to take either the CIH or CSP examination. Its purpose is to recognize technologists in the fields of safety and health.

There has been an orderly development of safety knowledge, which, when applied with sufficient skill and judgment, has produced significant reductions in occupational disease and in many types of accidents and accidental injuries. However, the tremendous increase in scientific knowledge and technological progress has added to the complexities of safety work.

The focus on the control of industrial disease and accident prevention has oscillated between environmental control or engineering and human factors. Some important trends in the pattern of the safety professional's development have emerged.

- ➢ First, increasing emphasis on analyzing the loss potential of the activity with which the safety professional is concerned; such analysis requires greater ability to predict where and how loss- and injury-producing events will occur and to find the means of preventing such events.
- ➢ Second, increased development of factual, unbiased, and objective information about loss-producing problems and accident causation, so that those who have ultimate decision-making responsibilities can make sound decisions.
- ➢ Third, increasing use of the safety professional's help in developing safe products. The application of the principle of accident causation and control to the product being designed or produced has become more important

because of product liability cases; legal aspects in the general field of safety and health, including negligent design; and the obvious impact that a safer product has on the overall safety and health of the environment.

CAREERS IN SAFETY

Protecting America's work force, the general public, and the environment from injury and illness in today's age of technological and scientific advancement has become one of the most challenging and rewarding career fields available. It is here that the safety professional brings to bear technical knowledge, skill, and expertise along with management abilities developed through years of education and practical experience.

There are many career options that one may pursue as a safety professional. The safety professional has the responsibility for studying materials, structures, codes, and operations in order to find the best way to use resources to control hazards, those things which can lead to accidents, illness, fires, explosions, etc. "Resources" may mean tools, equipment, machinery, buildings, or any other items that can prevent hazards. "Accidents" may cause injuries to people or damage to property and the environment as well as other adverse effects.

Safety managers recognize and devise methods to control hazards using the management skills and techniques needed to administer a department or facility. The safety manager may direct the safety program of a large plant, corporation, or a department within local, state or the federal government.

One very common career within the safety profession is that of a loss control representative for an insurance organization. These professionals help organizations which are insured or seeking to be insured identify risks within their operations and reduce the possibility of accidents, fires, and other losses.

The broad field of safety is concerned with the interaction between people and the physical, chemical, biological, and psychological forces which affect their well-being. It is necessary to realize that all of these forces influence or affect people simultaneously; therefore the safety professional cannot study one area without considering the effects of the others.

The largest employers of safety professionals are manufacturing, service industries, construction, insurance, consulting firms, and the government.

DEFINITION OF A SAFETY PROFESSIONAL

What, then, is a safety professional? The Board of Certified Safety Professionals of the Americas, Inc., has identified a *safety professional* as a person engaged in the prevention of accidents, incidents, and events that harm people, property, or the environment. They use qualitative and quantitative analysis of simple and complex products, systems, operations, and activities to identify hazards. They evaluate the hazards to identify what events can occur and the likelihood of occurrence, severity of results, risk (a combination of probability and severity), and cost (Figure 24–3). They identify what controls are appropriate and their cost and effectiveness. Safety professionals make recommendations to managers, designers, employers, government agencies, and others. Controls may involve administrative controls (such as plans, policies, procedures, training, etc.), engineering controls (such as safety features and systems, fail-safe features, barriers, and other forms of protection), and personal protective equipment (PPE). Safety professionals may manage and implement controls.

HAZARD IDENTIFICATION CHECKLIST TYPE 1—SAFETY

1A. INTERNAL ENERGY RELEASE

1A1	ENERGY SOURCES	POTENTIAL	(PRESSURE VESSEL)
		KINETIC	(CENTRIFUGE)
		CHEMICAL	(FUEL, EXPLOSIVES)
1A2	UNSAFE CONDITIONS (INCLUDES HARDWARE UNRELIABILITIES)		
1A3	HUMAN ERROR (CONSIDER PROGRAM OR TRAINING DEFICIENCY)		

1B. EXTERNAL ENERGY DAMAGE

1B1	SYSTEM ENVIRONMENTS (SHOCK, TEMPERATURE, CONTAMINATION)
1B2	NATURAL ENVIRONMENTS (LIGHTNING, EARTHQUAKE, HURRICANE)

1C. PHYSIOLOGICAL DAMAGE

1C1	TOXIC SOURCES (POISON GASES, X-RAYS, NOISE)
1C2	DEPRIVATIONS (ANOXIA, STARVATION, DEHYDRATION)

Figure 24–3. Hazard evaluation and abatement checklists are very useful in pinpointing safety and health hazards. (Adapted from Workplace Injury and Illness Prevention, CS–1A. Cal. OSHA Consultation Service.)

Figure 24–4. Personal protective equipment is commonly used to protect employees from potentially hazardous operations.

Besides knowledge of a wide range of hazards, controls, and safety assessment methods, safety professionals must have knowledge of physical, chemical, biological and behavioral sciences, mathematics, business, training and educational techniques, engineering concepts, and particular kinds of operations (construction, manufacturing, transportation, etc.).

Accident Prevention Activities

The basic accident prevention activities (in descending order of effectiveness and preference) are as follows:

- ➢ Eliminate the hazard from the machine, method, material, or facility structure.
- ➢ Control or contain the hazard by enclosing or guarding it at its source or exhausting an airborne hazard away from the operator.
- ➢ Train operating personnel to be aware of the hazard and to follow safe job procedures to avoid it.
- ➢ Prescribe personal protective equipment for personnel to shield them from the hazard (Figure 24–4).

It is beyond the scope of this section to describe completely all accident prevention activities of safety professionals at each operation. However, the primary responsibilities are outlined here:

- ➢ Provide advisory services on safety and health problems and other matters related to accident prevention.
- ➢ Develop a centralized program to control hazards.
- ➢ Keep informed of changes in federal, state, and local safety codes, and communicate such information to management.
- ➢ Develop and apply safety standards both for production facilities (equipment, tools, work methods, and safeguarding) and for products, based on applicable legal and voluntary codes, rules, and standards.
- ➢ Work closely with the engineering, industrial hygiene, medical, and purchasing departments during the development and construction of new equipment and facilities. See that a procedure is established to ensure that only safe tools, equipment, and supplies are purchased; advise the purchasing department on acceptable supplies and materials; and review and approve purchase requisitions for personal protective equipment and safety items.
- ➢ Develop, plan, and implement the safety and health inspection program carried out by the operating supervisors and field safety personnel to identify potential hazards, both in the workplace and in the use of the organization's products. Inspect all new equipment in conjunction with engineering, operating, and personnel representatives for adequate safeguards and freedom from major safety and health hazards.
- ➢ Guide operating supervision in accident investigation to determine the accident's cause and to prevent recurrence. Review nondisabling-injury accident reports on a sample basis to check the thoroughness of the accident investigation and corrective actions taken.
- ➢ Collect and analyze data on illness and accidents for the purpose of instituting corrective action and to determine accident trends and provide targets for corrective action. Maintain such files as those of inspection records, employee training, OSHA injury and illness logs, a hazard log, and files of complaints and suggestions.
- ➢ Ensure education and training of employees in general and specific safety and health principles and techniques (Figure 24–5). Maintain supervisory contacts for new instructions, follow-up, and general safety and health motivation.
- ➢ Cooperate with medical personnel on matters of employee health and fitness to work, and with industrial hygiene or environmental quality control personnel on industrial hygiene problems.

SAFETY AND HEALTH PROGRAMS

Management usually places administration of the accident prevention or safety and health program in the hands of a safety professional whose title is safety director, manager of

Figure 24–5. Educating employees about the importance of general health and safety principles and techniques is one of the mainstays of an effective health and safety program.

safety, or loss control manager.

Full staff responsibility for the safety activities should be assigned to one person. The decision concerning proper placement of responsibility should be based on the size of the organization and the nature of the hazards involved in its operation.

Employment of full-time safety professionals is increasing for the following reasons:

- The passage of the Occupational Safety and Health Act (OSHA) of 1970 requires that certain safety standards be met and maintained.
- A better understanding of the safety professional's services and functions is developing. To administer a safety program effectively, the individual in charge must be highly trained and/or have many years of experience in the safety field.

A safety and health program is not something that is imposed on organization operations as an afterthought. Safety, an integral part of organization operations, must be built into every process or product design and into every operation and procedure.

The prevention of accidents, illness, and injuries is basically achieved through control of the working environment and control of people's actions. The safety professional can assist management to implement such control.

An organization with an effective health and safety program has a working environment in which operations can be conducted safely, economically, and efficiently, with a minimum of employee, customer, and public complaints.

STAFF VERSUS LINE STATUS

In general, the safety and health program is administered by safety professionals or other persons holding line positions in a small company, or staff positions in a large organization. In large corporations, the safety professionals and their organizations usually have staff status and authority. The exact organizational status of the safety staff is determined by each firm in terms of its own operating policies.

The safety and health program as a staff function should have the following objectives:

- To establish staff credibility to advise and counsel regarding safety or health matters
- To keep all affected personnel adequately informed regarding safety or health matters
- To ensure that responsibility and accountability for safety are properly assigned with every staff group and operating management
- To program activities that support harmonious supervisor/employee interaction on safety or health matters
- To establish and reinforce consistent attention to preventive practices and actions

Sometimes the safety professional is delegated authority that is usually reserved for line officials. On fast-moving and rapidly changing operations; operations on which delayed action would endanger the lives of workers or others, as in construction and demolition work, fumigation, and chemical processes or processes with other dangerous substances; or emergency work, it is common to find that the safety professional has authority to order immediate changes, including the shutting down of specific equipment or operations.

CODES AND STANDARDS

The safety professional must be familiar with codes and standards applicable to equipment, material, environmental controls, and energy sources. Only by knowing which codes and standards apply can the safety professional give valid advice regarding organization standards for purchasing specifications. The safety professional must know how to meet government agency regulatory requirements (such as those of OSHA, EPA, and the Mine Safety and Health Administration [MSHA], but there are also many other guidelines and consensus standards that provide state-of-the-art models. Therefore, the safety professional should be familiar with the following:

- Codes and standards approved by the American National Standards Institute (ANSI) and other standards and specifications groups (see Bibliography).
- Codes and standards adopted or set by federal, state, and local government agencies. This is particularly important where local or state codes are more stringent than federal codes.
- Codes, standards, and lists of approved or tested devices published by such recognized authorities as Underwriters Laboratories, Inc., and the National Fire Protection Association.
- Safety practice recommendations of such organizations as the National Safety Council, American Society of Safety Engineers (ASSE), American Conference of Governmental Industrial Hygienists (ACGIH), American Industrial

Hygiene Association (AIHA), insurance carriers or their associations, and trade and industrial organizations.

Policies and Procedures

One of the main tasks confronting the safety professional is the development and implementation of organization safety and health policies and procedures. Policies and procedures are necessary to ensure that OSHA and organization requirements for safety and health are carried out uniformly within an organization. Examples of policies and procedures that many companies would have in a safety and health program might include visitor safety, accident investigation, safety meetings, new employee safety and health orientations, first aid/CPR, reporting injuries and illnesses, hazard communication, confined spaces, materials handling and lifting, personal protective equipment including respiratory protection, bloodborne pathogens, ergonomics, and fleet/vehicle safety.

Because safety and health policies and procedures often affect a number of departments and have far-ranging effects in terms of operations and costs, they must be reviewed by management as well as the safety professional.

Policies and procedures generally begin with a purpose statement. In other words, what is the policy and procedure intended to accomplish? The purpose statement is often followed by general requirements and a procedure, including designation of individuals or positions along with their specific tasks or action steps.

An important duty of the safety professional should be that of checking plans for new or remodeled facilities and new, rebuilt, or rearranged equipment; changes in material used in product or processes and material-storage and handling procedures; and plans for future products (Figure 24–6). Many companies do not permit a drawing or specification to be used until it has been approved by the safety professional. This important function must be done early enough to afford an opportunity to discover health and safety hazards and to correct conditions that might otherwise be built into the facility and its equipment and that would later result in injuries or other casualty losses. There is also the opportunity at this planning stage to build in safety or fire protection features and to provide adequate space for exit aisles, janitor closets, waste-collection equipment, and other commonly overlooked functions.

Figure 24–6. As a production process is being planned, staff from engineering, production, and safety meet to review drawings and plans to incorporate safety and health features.

The safety professional should also make sure that organization policies and applicable standards are followed in purchase specifications for new materials and equipment and for modification of existing equipment. Some companies have arranged for the purchasing department to notify the safety department when new materials or equipment are to be purchased, or when there is a new supplier of safety-related materials. For instance, when a new chemical is requested, the safety department should ensure that any applicable Material Safety Data Sheet (MSDS) is obtained from the manufacturer.

The engineering department, with the help of the safety professional, should check with the purchasing department to determine the necessary safety and health measures to be built on or into a machine before it is purchased. Purchasing agents in an industrial facility are necessarily cost-conscious. Consequently, the safety professional must know the occupational disease and accident losses to the organization in terms of specific machines, materials, and processes. If the professional is to recommend the expenditure of several thousand dollars for protection of health or other safeguards to be used throughout the facility, for instance, there should be valid evidence that the investment is justified.

Because of highly competitive marketing, manufacturers of machine tools and processing equipment often list safety devices, such as guards and noise enclosures designed for the protection of operators, as separate auxiliary equipment. The supplier may not know the ultimate use of the product. The actual needs for guards and automatic controls depend on the proximity of the operator to the equipment and vary from one installation to another. The safety professional must evaluate each installation and be in a position to satisfy the purchasing agent of the need for health and safety equipment to be included in the original order, or to recommend the issuance of additional purchase orders to provide adequate protection to the operator.

In many organizations, safety and health functions are placed in three coordinate departments:

- The engineering department, where plans and specifications are prepared for all machinery and equipment purchased
- The safety and health department, where plans and specifications are carefully checked for safety and health
- The purchasing department, which has much latitude in making selections and determining standards of quality, efficiency, and price

Note that even in smaller organizations, someone must be responsible for these three functions for an effective safety and health program.

Engineering

The ultimate objective of an organization's engineering program is to design equipment and processes and to plan work procedures so that the organization can produce the best product with the highest quality at the lowest cost. It is the safety professional's job to see that engineering personnel are acquainted with the particular safety and health hazards involved and to suggest methods of eliminating these hazards.

The goal is to design safe and healthful environments and equipment and to set up job procedures so that employee exposure to the hazards of illness and injury are either eliminated or controlled as completely as possible. This can be accomplished when safety and health are factors incorporated into the design of the equipment or the planning of the process, along with adequate training and supervision.

The most efficient time to engineer safety and health hazards out of the facility, product, process, or job is before building or remodeling, while a product is being designed, before a change in a process is put into effect, or before a job is started. Every effort, therefore, should be made to find and remove potential safety and health hazards at the blueprint or planning stage.

Machine and Equipment Design

The machine manufacturer, like any other business, wants to have satisfied customers. If the machines cause accidents, customers are dissatisfied. If a customer's order for a machine specifies that the machine must meet specific regulations of OSHA (or another agency) and have safety built into it, the manufacturer's designers will regard such a specification as a design requirement that they must meet. If only a general statement such as "must meet OSHA standards" is used, the manufacturer does not know which standards apply, and the equipment may not be properly guarded.

In many instances, guards added to a machine after it has been installed in a facility are easily removed, and often are not replaced. If a guard or enclosure is an aid to production and efficiency rather than a hindrance, however, it is unlikely that the machine would be operated without having the guard in place. Machine safety must be improved without hindering the worker or reducing the efficiency of the equipment. (See Bibliography for more information.)

The best solution lies in a basic guard design that eliminates the safety and health hazard and, if possible, increases efficiency. There can be little prospect for safe operation of a machine unless the idea of building safety and health measures into the machine's function is applied right on the drawing board for the establishment that is going to use the equipment.

Purchasing

The safety professional is responsible for generating and documenting safety and health standards to guide the purchasing department. These standards should be set up so that the safety and health hazards associated with a particular kind of equipment or material being purchased are eliminated or, at the very least, substantially reduced.

The purchasing staff, although not directly involved with educational and enforcement activities, is vitally concerned with many phases of engineering activities. They select and purchase the various items of machinery, tools, equipment, and materials used in the organization, and it is to a considerable degree their responsibility to see that safety has received adequate attention in the design, manufacture, and particulars of shipment of these items.

The safety professional should be well prepared to advise the purchasing department when required to do so. The purchasing staff can reasonably expect the safety professional to offer the following:

- Specific information about safety and health hazards that can be eliminated by change in design or application of guarding by the manufacturer
- Information about equipment, tools, and materials that can cause injuries if misused
- Specific information about health and fire hazards at the facility's worksites
- Information on federal and state safety and health rules and regulations
- Information on accident experience with machines, equipment, or materials that are about to be reordered

SAFETY AND HEALTH CONSIDERATIONS

In purchasing items such as lifting devices and automatic packaging, chemical processing, or storage equipment, safety and health concerns are extremely important. For example, extreme caution must be observed in the purchase of personal protective equipment, including eye protection, respirators, gloves, and the like; of equipment for the movement of suspended loads, such as ropes, chains, slings, and cables; of equipment for the movement and storage of materials; and of miscellaneous substances and fluids for cleaning and other purposes that might constitute or aggravate a fire or health hazard. Adequate labeling that identifies contents and calls attention to safety and health hazards should be specified. This labeling must comply with state or federal hazard communication (right-to-know) standards. Because the rules and regulations of federal and state agencies keep changing, the safety professional must keep up to date on both employee and community right-to-know regulations.

Many commonly unsuspected safety and health hazards must be considered when very ordinary items such as common hand tools, reflectors, tool racks, cleaning rags, and paint for shop walls and machinery are purchased. Among the factors to be considered are maximum load strength; long life without

Figure 24–7. Periodic safety inspections are conducted to recognize and evaluate potential health and safety hazards before an accident occurs.

deterioration; sharp, rough, or pointed characteristics of articles; need for frequent adjustment; ease of maintenance; and ergonomic factors that result in excessive fatigue. Where toxic chemicals are involved, disposal of residue, scrap, and shipping containers must be considered. Safety professionals who are in day-to-day contact with the operating problems must give such information to the purchasing agent.

SAFETY AND HEALTH INSPECTIONS

Safety inspections are one of the principal means of locating potential causes of accidents and illness and help determine what safeguarding is necessary to protect against safety and health hazards before accidents and personal injuries occur.

Just as inspections of a process are important functions in quality control, safety and health inspections are important in accident control (Figure 24–7).

Inspections should not be limited to a search for unsafe physical conditions but should also try to detect unsafe or unhealthful work practices. Finding unsafe conditions and work practices and promptly correcting them is one of the most effective methods of preventing accidents and safeguarding employees. Management can also show employees its interest and sincere effort in accident prevention by correcting unsafe conditions or work practices immediately. Inspections help to "sell" the safety and health program to employees. Each time a safety professional or an inspection committee passes through the work area, management's interest in safety and health is advertised. Regular facility inspections encourage individual employees to inspect their immediate work areas.

In addition, inspections facilitate the safety professional's contact with individual workers, thereby making it easier to obtain their help in eliminating accidents and illnesses. The workers can often point out unsafe conditions that might otherwise go unnoticed and uncorrected. When employee suggestions are acted on, all employees are made to feel that their cooperation is essential and appreciated.

Safety and health inspections should not be conducted primarily to find out how many things are wrong, but rather to determine whether everything is satisfactory. Their purpose should be to discover conditions that, if corrected, will bring the facility up to accepted and approved safety and health standards and result in making it a safer and more healthful place in which to work. When observed, inspectors should tactfully point out any unsafe work procedures to the employees involved. They should be certain to indicate the hazards. Inspectors may need to recommend new or continuing safety and health training for supervisors and employees.

Inspection of Work Areas

Before the facility walk-through inspection, it is advisable to review reports of all accidents (including noninjury accidents and near misses, if possible) for the previous several years, so that special attention can be given to the conditions and locations known to be safety-sensitive.

Most facilities make use of irregularly scheduled inspections, which can include an unannounced inspection of a particular department, piece of equipment, or small work area. Such inspections made by the safety department tend to keep the supervisory staff alert to find and correct unsafe conditions and operating practices before they are found by the safety inspector.

The need for intermittent inspections is often indicated by accident report analysis. If the analysis shows an unusual number of accidents for a particular department or location or an increase in certain types of injuries, an inspection should be conducted to determine the reasons for the

increase and to find out what corrections are necessary. All results of inspections must be discussed with operating supervision if any gain is to be made.

Supervisors should constantly ensure that tools, machines, and other department equipment are maintained properly and are safe to use. To do this effectively, they should use systematic inspection procedures and can delegate authority to others in a department.

Inspection programs should be set up for new equipment, materials, procedures, and processes. A process should not be put into regular operation until it has been checked for hazards; additional safeguards have been installed, if necessary; and safety instructions or procedures have been developed. This is also a good time to make a complete job safety analysis (JSA) of the operation. It takes less time and effort now than if done later.

Safety Inspectors or Technicians

Inspectors should know how to locate safety and health hazards and should have the authority to act and make recommendations. A good safety inspector must know the organization's accident experience, be familiar with accident potentials, have the ability to make intelligent recommendations for corrective action, and be diplomatic in handling situations and personnel.

Safety inspectors must be equipped with the proper personal protective equipment, protective clothing, and other required equipment to carry out duties. It would be difficult for a safety inspector to persuade an employee to wear eye protection or safety shoes if the inspector does not wear them, or to require workers to use respirators unless the inspector sets the example and uses one in a hazardous environment. It is essential that inspectors practice what they preach.

Safety Professionals

The safety professional has a productive role during safety inspections, coordinating the safety program and teaching by first-hand contact and on-the-spot examples.

The number of safety professionals and inspectors needed for adequate safety inspection activities depends a great deal on the size and complexity of the facility and the type of industry involved. Large companies with well-organized safety programs usually employ a staff of full-time safety professionals and inspectors who work directly under a safety director or safety supervisor. Some large companies also have specially designated employees who spend part of their time on inspections, and some have employee inspection committees.

The safety professional should be fully in charge of developing safety inspection activities and should receive the reports of all inspectors. Special departmental inspectors should either make safety inspections personally or supervise the inspectors in their work. Although safety professionals often have a considerable amount of office work to do, they should get out into the production and maintenance areas as often as possible and make general as well as specific safety inspections. If there is more than one facility involved, there should be a plan to make at least an annual inspection survey of each facility.

Third-Party Inspections, or Audits

The value of a third-party inspection of policies, procedures, and practices as well as an inspection of the physical facility and equipment is increasingly evident. The advantages of such audits are as follows:

- ➢ Objectivity of the inspecting party is less likely to lead to biased findings or their reporting.
- ➢ Results of external audits are usually directed to a higher level of decision-making authority and thus are more likely to be acted on promptly.
- ➢ Performance of the audit does not have to depend on the time or convenience of organization staff.
- ➢ Professionals contracted for such audits usually have much expertise in a given industry.

Many businesses currently find that an annual audit and inspection of their facilities to assess the state of their safety, health, and environmental affairs is as important as the traditional financial audit. Results of these third-party audits are often included in the organization's annual report. More information on third-party audit services is often available from insurance carriers, independent safety/health consulting firms, OSHA Consultation Services, or the National Safety Council.

ACCIDENT AND OCCUPATIONAL ILLNESS INVESTIGATIONS

Purpose of Investigations

Investigation and analysis are used by safety professionals to prevent accidents, both those that could result in injury to personnel and those that do not. The investigation or analysis of an accident can produce information that leads to countermeasures to prevent accidents or reduce their number and their severity. The more complete the information, the easier it is for the safety professional to design effective control methods. For example, knowing that 40 percent of a facility's accidents involve ladders is useful, but it is not as useful as also knowing that 80 percent of the ladder accidents involve broken rungs.

An investigation of every disabling injury or illness must be made. Incidents resulting in nondisabling injuries or no injuries and "near accidents" should also be investigated to evaluate their causes in relation to injury-producing accidents or breakdowns, especially if there is frequent recurrence of certain types of nondisabling injuries or if the frequency of accidents is high in certain areas of operations.

The consequences of certain types of accidents are so devastating that any hint of conditions that might lead to their occurrence warrants an investigation. In such cases, any change from standard safety specification that has been made warrants a thorough investigation.

For purposes of accident prevention, investigations must be fact-finding, not fault-finding; otherwise, they may do more harm than good. However, this is not to say that responsibility should not be fixed when personal failure or negligence has caused injury, or that such persons should be excused from the consequences of their actions.

Types of Investigations

There are several accident investigation and analysis techniques available. Some of these techniques are more complicated than others. The choice of a particular method depends on the purpose and orientation of the investigation.

The accident investigation and analysis procedure focuses primarily on unsafe circumstances surrounding the occurrence of an accident, and it is the most often-used technique. Other similar techniques involve investigation within the framework of defects in man, machine, media, and management (the "four Ms"), or education, enforcement, and engineering (the "three Es of safety") should be analyzed.

Accident investigation techniques involve classifying the data about a group of accidents into different categories for analysis. This is known as the statistical method of analysis. Control methods are designed on the basis of most frequent patterns of occurrence.

Other techniques are discussed later in this chapter under the systems approach to safety. Systems safety stresses an enlarged viewpoint that takes into account the interrelationships between the various events that could lead to an accident. Because accidents rarely have a single cause, the systems approach to safety can lead to the discovery of more than one place in a system where effective controls can be introduced. This allows the safety professional to choose the control methods that best meet criteria for such factors as effectiveness and speed of installment. Systems safety techniques also have the advantage of application before accidents or illnesses occur, and can be applied to new procedures and operations.

Who Conducts the Investigation?

Depending on the nature of the accident and other conditions, the investigation can be conducted by the supervisor, the safety engineer or inspector, the workers' safety and health committee, the general safety committee, the safety professional, or a loss control specialist from the insurance organization or other external source. Also, OSHA requires that fatalities and/or accidents resulting in serious injury be reported to them. Depending on the circumstances surrounding the fatality, serious injury, or illness, an OSHA inspection may result and should be anticipated by the employer. Regardless of who conducts the initial investigation, a representative of the organization's safety department should verify the findings and direct a written report to the proper official or to the general safety committee.

The safety professional's value and ability are best shown in the investigation of an accident. Specialized training and analytical experience enable the professional to search for all the facts, both apparent and hidden, and to submit an unbiased report. The safety professional should have no interest in the investigation other than to get information that can be used to prevent a similar accident.

During an investigation, methods to prevent a recurrence can be identified, but decisions about the specific course to take are best made after all the facts are well-established. There are usually several alternatives; all must be fully understood in order for the most effective decision to be made. The safety professional should present every valid, feasible alternative to operating management for their consideration. At this stage, input from employees can be highly beneficial in determining the best corrective measure.

RECORD KEEPING AND REPORTING

The Williams-Steiger OSHAct of 1970 requires employers to maintain records of work-related employee injuries and illnesses, as well as many inspection reports of high-injury–potential equipment. In addition, many employers are also required to make reports to state compensation authorities.

Safety professionals are faced with two tasks: maintaining those records required by law and by their management, and maintaining records that are useful in an effective safety program. Unfortunately, the two are not always synonymous. A good record-keeping system necessitates more data than those called for in almost all OSHA-required forms. In general, OSHA and related safety records need to be "readily available." How the employer chooses to maintain those records (i.e., hard (paper) copy, computerized) is generally a business decision.

Many different safety records must be maintained, and OSHA has established how long many of these records must be maintained by the employer.

Records that must be generated and maintained include records of inspections; accident investigations; general and specific training; medical and exposure monitoring results; the OSHA log of injuries and illnesses; fatality and serious injury and illness reports to OSHA; insurance records such as the employer's and doctor's first reports of injury and illness; and respirator-fit test and other personal protective equipment records addressing the maintenance, use, selection, inspection, and storage of such equipment.

Records of accidents, injuries, and illnesses and the training experience of the people involved are essential to efficient and successful safety programs, just as records of production, costs, sales, and profits and losses are essential to efficient and successful operation of a business. Records supply the information necessary to transform haphazard, costly, ineffective safety and training efforts into a planned

safety and health program that enables control of both conditions and acts that contribute to accidents. Good record keeping is the foundation of a scientific approach to occupational safety.

Uses of Records

A good record-keeping system can help the safety professional in the following ways:

- ➢ It provides safety personnel with the means for an objective evaluation of the magnitude of occupational illness and accident problems and with a measurement of the overall progress and effectiveness of the safety and health program.
- ➢ It helps identify high-hazard units, facilities, or departments and problem areas so that extra effort can be made in those areas.
- ➢ It provides data necessary for an analysis of accidents and illnesses that can point to specific circumstances of occurrence, which can then be attacked by specific countermeasures.
- ➢ It can create interest in safety and health among supervisors by furnishing them with information about the accident and illness experience of their own departments.
- ➢ It provides supervisors and safety committees with hard facts about their safety and health problems so that their efforts can be concentrated.
- ➢ It helps in measuring the effectiveness of individual countermeasures and determining whether specific programs are doing the job that they were designed to do.
- ➢ It can help establish the need for, and the content of, employee and management training programs that can be tailored to fit the particular needs of that organization or facility.

Accident Reports and Illness Records

To be effective, preventive measures must be based on complete and unbiased knowledge of the causes of accidents and the knowledge of the supervisor and employee about the operation. The primary purpose of an accident report, like the inspection, is to obtain information, not to fix blame. Because the completeness and accuracy of the entire accident record system depend on information in the individual accident reports and the employee training history, it is important that the forms and their purpose are understood by those who must fill them out. Essential training or instruction by the safety professional should be given to those who are responsible for generating the information. (Illustrations of typical forms are given in the latest editions of the National Safety Council's *Accident Investigation, Accident Prevention Manual for Business & Industry*, vol. 1: *Administration & Programs*, and the *Supervisors' Safety Manual*—see Bibliography.) Photographs, videotapes, and drawings of the accident or a depiction of the accident can be extremely useful.

THE FIRST-AID REPORT

Collecting injury or illness data generally begins in the first-aid department. The first-aid attendant or the nurse fills out a first-aid report for each new case. Copies are sent to the safety department or safety committee, the worker's first-line supervisor, and other departments as management designates.

The first-aid attendant or the nurse should know enough about accident analysis and illness investigation to be able to record the principal facts about each case. Note that the questioning of the injured or sick person must be complete enough to establish whether the incident is or is not work-related. Current emphasis on chemical air contaminants makes it necessary to include or exclude exposure to known health hazards. First-aid reports can be very helpful to the safety or industrial hygiene personnel. The organization's physician who treats injured employees should be informed of the basic rules for classifying cases because, at times, the physician's opinion of the severity of an injury is necessary to record the case accurately.

THE SUPERVISOR'S ACCIDENT REPORT FORM

This should be completed as soon as possible after an accident occurs, and copies sent to the safety department and to other designated persons. Information concerning unsafe or unhealthful work conditions and improper work practices is important in the prevention of accidents, but information that shows why the unsafe or unhealthful conditions existed can be even more important. This type of information is particularly difficult to get unless it is obtained promptly after the accident occurs. If the information is based on opinion, not on proven facts, it is still important, but should be so identified.

Generally, analyses of accidents are made only periodically, and often long after the accidents have occurred. Because it is often impossible to accurately recall the details of an accident, this information must be recorded accurately and completely at once or it may be lost forever.

INJURY AND ILLNESS RECORD OF AN EMPLOYEE

The first-aid report and the supervisor's report contain information about the agency of injury (type of machine, tool, or material), the type of accident, and other factors that facilitate the use of the reports for accident prevention. Another form must be used to record the injury experience of individual employees.

The employee training record card should have space to record injury information such as the date, classification, days charged, and costs.

Much can be learned about accident causes from studying employee injury records. If certain employees or job classifications have frequent injuries or illnesses, a study of the work environment, job training, safety and health training, work practices, and the instructions and supervision given them may reveal more than a study of accident locations, agencies, or other factors.

EDUCATION AND TRAINING

It is critical that safety and health training begins at the time of hiring, before the employee actually starts work on a particular task. Employees who are new to an organization, a task, or use of a material are at greatest risk for injuries and illnesses. An effective safety and health training program includes a carefully prepared and presented introduction to the organization.

New employees immediately begin to learn and form attitudes about the organization and their job, boss, and coworkers, whether or not the employer offers a training program. To encourage a new employee to form positive attitudes, it is important for the employer to provide a sound basis for them, and providing safety and health information is vital. Training about exposure to chemical hazards in the workplace is now mandated by state and federal hazard communication standards (right-to-know laws). (See Chapter 28, Government Regulations, for more information on these and other relevant regulations and standards.) In fact, most new OSHA regulations generally have a training requirement written into the standard.

An effective accident prevention and occupational health hazard control program is based on proper job performance. When people are properly trained to do their jobs, they do them safely. This means that supervisors must know what employee training needs to be given, which means knowing the requirements of the job; know how to train an employee in the safe way of doing a job; and know how to supervise. It also means the safety professional should be familiar with good training techniques. Although the professional is not always directly involved in the training effort, he or she should be able to recognize the elements of a practical training program.

A training program is needed for new employees, when new equipment or processes are introduced, when procedures are revised or updated, when new information must be made available, when employee performance must be improved, when new or unexpected hazards are uncovered, and on a periodic basis to refresh employees' knowledge of the material. Employees with longer tenure also need training so that they have the same information about new equipment, products, or organizational policies that new employees are receiving.

Many supervisors acquired their present positions in organizations where some sort of safety and health program already existed, and their understanding of the program is firmly established. However, a safety professional undertaking the safety training of supervisors almost invariably finds that the first major job is to get supervisors at all levels to understand and accept their role in accident and illness prevention. This job cannot be done in a single meeting or through a single communication.

Simply getting supervisors to agree in theory that responsibility for safety and health is one of their duties is not enough. They must come to understand the many ways in which they can prevent illness and accidents, and they must become interested in improving their safety performance. For a safety and health program to be effective, all levels of management must be firmly committed to the program and express that commitment by action and example. Management is ultimately responsible for the safety and health of the employees. Much of the effort put into an industrial safety and health program by a safety professional is, therefore, directed toward educating and influencing management.

Employee Training

The training of an employee begins the day the employee starts the job. As observed earlier in this chapter, whether or not the firm has a formal safety and health orientation program, the employee starts to learn about the job and to form attitudes about many things—including safety and health—on the first day.

The safety professional assists supervisors in instructing employees in the safe way of doing each job. Accidents can be prevented only when these recommended procedures are based on a thorough analysis of the job and when the procedures are followed. This is why a complete job safety analysis is so valuable (Figure 24–8). It provides a baseline for future comparison, and it details all necessary safety elements of the various job tasks.

The safety professional can provide supervisors with methods for observing all workers in the performance of their tasks to establish the job safety requirements, and should participate in follow-up observations to reinforce the supervisors' training. In this way, supervisors are informed of any weakness in the organization's safety and health program and will have a common reference point for monitoring these problems.

TRAINING TIPS

- ➢ Train small groups whenever possible. Employees seem to learn more and are more apt to ask questions in small training groups.
- ➢ Consider providing two levels of training, one for the supervisor and another for the workers. Generally, supervisory training needs to be more comprehensive than that given to workers.
- ➢ Consider using outside trainers. Oftentimes employees perceive outside trainers and consultants as having a higher level of credibility.
- ➢ Make use of commercially available audiovisual information (video tapes, slides, and films). It is important to screen these commercial products, because they are often very generic and must be supplemented with site-specific information and discussions. Many trade associations have produced audiovisual information for their member companies.
- ➢ Keep records of employee attendance. Note the date, subjects covered, instructor, and training aids used (such

as videos, Internet training modules), and make a list of attendees (with their signatures if possible). A copy of any tests given and of the agenda should be kept on file as well.

- ➢ With the development and popularity of internet training, it is important to consider that much of this training is very good, however, fairly generic in nature. Employees must be trained and informed in general and specific safety and health measures necessary to do their jobs safely.
- ➢ Make the training as participatory as possible. Encourage discussions, use training aids, and practice the use of equipment and procedures discussed in the training.

Maintaining Interest in Safety

A prime objective of a good safety and health program is to maintain interest in safety in order to prevent accidents. It is, however, as difficult to determine the degree of success achieved by an interest-maintaining effort as part of a safety program as it is to isolate the effectiveness of an advertising campaign separate from an entire marketing program. The reason is that companies with sound basic safety and health programs generally have working conditions that are safe, employees who are well trained and safety minded, and high-caliber supervision.

Safety and Health Rule Enforcement

Obeying safety and health rules is actually a matter of education; employees must understand the rules and the importance of following them. In helping an employee understand, the possibility of language barriers should be considered. Language barriers are caused not only by national origins but also, and more often, by the jargon of a particular profession or industry. A considerable amount of confusion can occur when a new employee comes from a different industry or field of work.

Role of the Supervisor

Supervisors are the key people in any program designed to create and maintain interest in safety and health, because they are responsible for translating management's policies into action and for promoting safe and healthful work practices directly among the employees. The supervisors' attitudes toward safety and health are a significant factor in the success of not only specific promotional activities but also the entire safety and health program, because their views will be reflected by the employees in their departments.

How well a supervisor meets this responsibility is determined to a large extent by how well the supervisor has been trained, and training and educating the supervisor in matters of safety and health is the responsibility of the safety professional.

Supervisor Training

Supervisors are often responsible for providing safety and health training to employees. They may be the primary safety trainers and have the final responsibility for the effectiveness of training. If the employer chooses to put the responsibility of training on supervisors, the employer must clearly communicate that this is a discrete responsibility. Just as important, the employer must ensure that the supervisor has the time, interest, and training necessary to provide adequate employee training.

Generally speaking, the supervisor needs training at a level equal to or exceeding the training given to labor. Several recent OSHA regulations have been adopted that require employers to provide additional training to supervisors. To illustrate, supervisors who supervise hazardous waste cleanup workers are required (29 *CFR* 1910.120) to take an additional 8 hours of management/supervisor training covering such topics as the employer's safety and health program, employee training program, personal protective equipment, and health hazard–monitoring procedures and techniques.

Many community colleges, independent training groups, and Internet training sites offer supervisory safety and health courses to better prepare supervisors for their safety and health tasks. Also, many organizations offer "train the trainer" courses.

The supervisor who is sincere and enthusiastic about accident prevention can do much to maintain interest because of a direct connection with the worker. Conversely, if the supervisor only pays lip service to the program or ridicules any part of it, this attitude offsets any good that might be accomplished by the safety professional.

Some supervisors may be reluctant to change their mode of operation and slow to accept new ideas. It is the safety professional's task to sell these supervisors on the benefits of accident prevention, and to convince them that promotional activities are not "frills" but rather projects that can help them do their job more easily and prevent illness and injuries. Also, safety has a direct relation to production and quality.

Setting a good example by wearing required personal protective equipment is an excellent way in which supervisors can promote the use of this equipment and demonstrate interest in safety. Teaching safety and health principles to supervisors is an important function of the safety professional; safety posters, a few warning signs, or merely general rules are not enough to do this job.

The safety professional should educate supervisors so that working conditions are kept as safe and healthful as possible and that the workers follow safe procedures consistently, as a routine part of good job performance. Supervisors are entitled to all of the help the safety professional can give through supplies of educational material for distribution and frequent visits to the jobsite, as circumstances permit. Supervisors should also receive adequate recognition for independent and original safety activity.

Supervisors can be very effective by giving facts and personal reminders on safety and health to employees as part of their daily work instructions. This procedure is particularly

National Safety Council
JOB SAFETY ANALYSIS
INSTRUCTIONS ON REVERSE SIDE

JOB TITLE (and number if applicable): Replacing a water bottle	PAGE 1 OF 2	JSA NO. 001	DATE: Today ☒ NEW ☐ REVISED
TITLE OF PERSON WHO DOES JOB: Maintenance/Janitor	SUPERVISOR: Eric Utney		ANALYSIS BY: Mary Green
COMPANY/ORGANIZATION: 123 Accounting Corp.	PLANT/LOCATION: General Office	DEPARTMENT: Reception	REVIEWED BY: Bill Camp
REQUIRED AND/OR RECOMMENDED PERSONAL PROTECTIVE EQUIPMENT: Protective footwear, non-slip gloves			APPROVED BY: Greg Porter

SEQUENCE OF BASIC JOB STEPS	POTENTIAL HAZARDS	RECOMMENDED ACTION OR PROCEDURE
1. Lift and load the bottle		
2. Transport the bottle and place near the dispenser		
3. Remove empty bottle from dispenser		
4. Position full water bottle on stand		
5. Check system		

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INSTRUCTIONS FOR COMPLETING THE JOB SAFETY ANALYSIS FORM

Job Safety Analysis (JSA) is an important accident prevention tool that works by finding hazards and eliminating or minimizing them *before* the job is performed, and *before* they have a chance to become accidents. Use JSA for job clarification and hazard awareness, as a guide in new employee training, for periodic contacts and for retraining of senior employees, as a refresher on jobs which run infrequently, as an accident investigation tool, and for informing employees of specific job hazards and protective measures.

Set priorities for doing JSA's: jobs that have a history of many accidents, jobs that have produced disabling injuries, jobs with high potential for disabling injury or death, and new jobs with no accident history.

Select a job to be analyzed. Before filling out this form, consider the following: The purpose of the job—What has to be done? Who has to do it? The activities involved—How is it done? When is it done? Where is it done?

In summary, to complete this form you should consider the purpose of the job, the activities it involves, and the hazards it presents. If you are not familiar with a particular job or operation, interview an employee who is. In addition, observing an employee performing the job, or "walking through" the operation step by step may give additional insight into potential hazards. You may also wish to videotape the job and analyze it.

Here's how to do each of the three parts of a Job Safety Analysis:

SEQUENCE OF BASIC JOB STEPS

Examining a specific job by breaking it down into a series of steps or tasks, will enable you to discover potential hazards employees may encounter.

Each job or operation will consist of a set of steps or tasks. For example, the job might be to move a box from a conveyor in the receiving area to a shelf in the storage area. To determine where a step begins or ends, look for a change of activity, change in direction or movement.

Picking up the box from the conveyor and placing it on a handtruck is one step. The next step might be to push the loaded handtruck to the storage area (a change in activity). Moving the boxes from the truck and placing them on the shelf is another step. The final step might be returning the handtruck to the receiving area.

Be sure to list *all* the steps needed to perform the job. Some steps may not be performed each time; an example could be checking the casters on the handtruck. However, if that step is generally part of the job it should be listed.

POTENTIAL HAZARDS

A hazard is a potential danger. The purpose of the Job Safety Analysis is to identify ALL hazards—both those produced by the environment or conditions and those connected with the job procedure.

To identify hazards, ask yourself these questions about each step:

Is there a danger of the employee striking against, being struck by, or otherwise making injurious contact with an object?

Can the employee be caught in, by, or between objects?

Is there potential for slipping, tripping, or falling?

Could the employee suffer strains from pushing, pulling, lifting, bending, or twisting?

Is the environment hazardous to safety and/or health (toxic gas, vapor, mist, fumes, dust, heat, or radiation)?

Close observation and knowledge of the job is important. Examine each step carefully to find and identify hazards—the actions, conditions, and possibilities that could lead to an accident. Compiling an accurate and complete list of potential hazards will allow you to develop the recommended safe job procedures needed to prevent accidents.

RECOMMENDED ACTION OR PROCEDURE

Using the first two columns as a guide, decide what actions or procedures are necessary to eliminate or minimize the hazards that could lead to an accident, injury, or occupational illness.

Begin by trying to: 1) engineer the hazard out; 2) provide guards, safety devices, etc.; 3) provide personal protective equipment; 4) provide job instruction training; 5) maintain good housekeeping; 6) insure good ergonomics (positioning the person in relation to the machine or other elements in such a way as to improve safety).

List the recommended safe operating procedures. Begin with an action word. Say exactly what needs to be done to correct the hazard, such as, "lift using your leg muscles." Avoid general statements such as, "be careful."

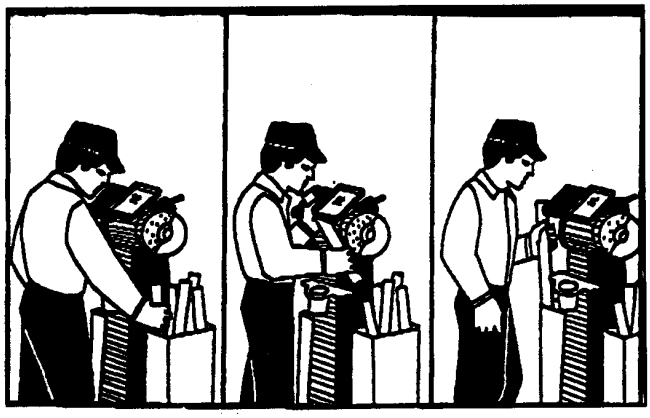
List the required or recommended personal protective equipment necessary to perform each step of the job.

Give a recommended action or procedure for each hazard.

Serious hazards should be corrected immediately. The JSA should then be changed to reflect the new conditions.

Finally, review your input on all three columns for accuracy and completeness. Determine if the recommended actions or procedures have been put in place. Re-evaluate the job safety analysis as necessary.

Figure 24–8. A job safety analysis form is used to record information that will be used as a baseline for future comparison and includes information on all necessary safety elements of the various job tasks. (Reprinted with permission from the National Safety Council. *Job Safety Analysis: Participant Workbook.* Itasca, Ill.: National Safety Council, 1994.)



Job Title: *Castings Grinding*

Job Location: *Machine Shop*

Job Step	*Potential Hazards*	*Recommended Action or Procedure*
1. Reach into metal box to right of machine, grasp casting and carry to wheel.	1. Strike hand on edge of metal box or casting; cut hand on burr. Drop casting on toes.	1. Provide gloves and safety shoes.
2. Push casting against wheel to grind off burr.	2. Strike hand against wheel. Flying sparks, dust or chips; wheel breakage. Not enough of wheel guarded. No dust removal system. Sleeves could get caught in machinery.	2. Provide larger guard over wheel. Install local exhaust system. Provide safety goggles. Instruct worker to wear short or tight-fitting sleeves.
3. Place finished casting in box to left of machine.	3. Strike hand against metal box or castings.	3. Provide for removal of completed stock.

Figure 24–9. A job safety analysis (JSA), even a simple one, breaks the job into steps and identifies hazards leading to the recommended action or procedure. Here is an employee performing a castings grinding operation.

necessary in the transportation and utility industries, where the work crews are on their own.

In any case, supervisors should be encouraged to take every opportunity to exchange ideas on accident prevention with workers, to commend them for their efforts to do the job safely, and to invite them to submit suggestions for better ways to do the job that will prevent injuries or illness.

Job Safety and Health Analysis

Job safety and health analysis (Figures 24–8 and 24–9) is a process used by safety professionals and supervisors to review job methods and uncover hazards. Once the safety and health hazards are known, the proper controls can be developed. Some controls are physical changes that control the hazard, such as enclosures to contain an air contaminant or a guard placed over exposed moving machine parts. Others are job procedures that eliminate or minimize the hazard, for example, safe stacking of materials. Procedure controls require training and supervision.

BENEFITS OF A JOB SAFETY ANALYSIS

The principal benefits that arise from job safety analysis are the establishment of the following practices:

- ➢ Individuals are given training in safe, efficient procedures.
- ➢ New employees are instructed on safety and health procedures.
- ➢ Preparations are made for planned safety and health observations.
- ➢ "Prejob" instructions are given on irregular jobs.
- ➢ Job procedures are reviewed after accidents occur.

New employees must be trained in the basic job steps. They must be taught to recognize the safety and health hazards associated with each job step and learn the necessary precautions. There is no better guide for this training than a well-prepared job safety analysis used with the job instruction training method.

All supervisors are concerned with improving job methods to increase safety, reduce costs, and step up production. The job safety analysis is an excellent starting point for questioning the established way of doing a job.

RISK MANAGEMENT
A Five-Step Program

Companies find they must control accidents if they are to continue to do business in a highly competitive market. One large organization uses an approach consisting of five closely related, logically ordered steps for a coordinated program. These steps are hazard identification, hazard elimination, hazard protection, determining the maximum possible loss, and loss retention.

HAZARD IDENTIFICATION

To prevent accidents and control losses, first identify all safety and health hazards to determine those areas or activities in an operation where losses can occur. This requires studying processes at the research stage, reviewing design during engineering, checking pilot facility operations and start-up, and regularly monitoring normal production.

HAZARD ELIMINATION

Toxic, flammable, or corrosive chemicals can sometimes be replaced by safer materials. Machines can be redesigned to eliminate danger points. Facility layouts can be improved by eliminating such hazards as blind corners and limited-visibility crossings.

HAZARD PROTECTION

Hazards that cannot be removed must be protected against. Familiar examples include mechanical guards to keep fingers from pinch points, safety shoes to safeguard toes against dropped objects, and ventilation systems to control the buildup of air contaminants. Industry is concerned with all

losses, injury to personnel, damage to products, and destruction of property.

MAXIMUM POSSIBLE LOSS

This step involves the determination of the maximum loss that could occur if everything went wrong. For example, entire buildings or areas can be lost as the result of a fire or explosion. The amount that an organization could lose under the most adverse conditions can be estimated.

LOSS RETENTION

Having some idea of the amount that could be lost under a combination of unfavorable circumstances, one can then determine what portion of such a loss an organization is willing to bear itself. Industrial companies can afford to retain a portion of each loss. The remaining loss potential is then insured through the organization's insurance carrier. This proves a good incentive for management to institute strong safety and health programs. These activities can be consolidated in one department such as a risk management department, bringing together the safety professional, fire protection manager, security and facility protection manager, occupational physician, occupational health nurse, industrial hygienist, environmental manager and insurance manager. The administrator of a total loss control program does not need to know all the details of each function, but should be able to develop an atmosphere in which there is harmonious cooperation and mutual understanding. Primary concerns are the control of occupational disease and personnel safety.

Damage Control

There should be a damage control program for investigating all accidents, not just those that produce injuries. This approach of studying accidents instead of injuries recognizes that a so-called no-injury accident, if repeated in the future, could result in personal injury, property damage, or both.

Ferreting out the causes of accidents reveals what unsafe conditions and/or work practices were responsible for the accident.

Three basic steps are successfully used to reduce property damage (and injuries): spot-checking, reporting by repair control centers, and auditing.

SPOT-CHECKING

Spot-checking consists of observing and taking notes to permit damage estimates by comparing total costs for a repair period with those found during sample observations.

REPORTING BY REPAIR CONTROL CENTERS

This step involves developing a system in which the repair or cost control center records property damage. The system should be designed to require the least possible amount of paperwork. No one system works in all companies, because repair cost–accounting methods vary greatly from organization to organization, and even from facility to facility within a single organization.

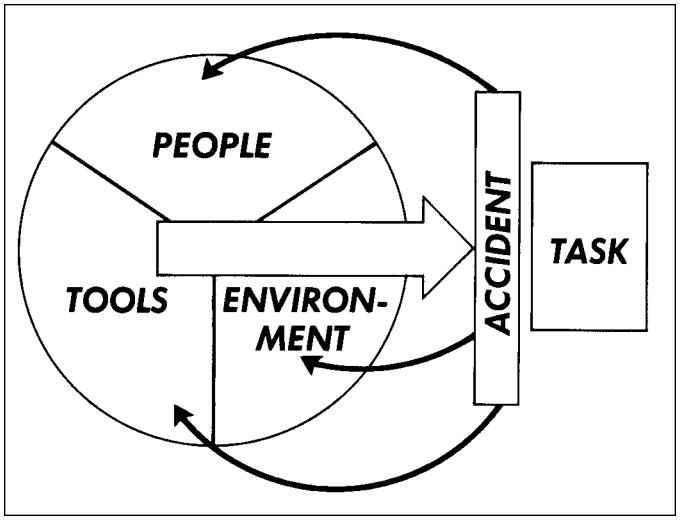


Figure 24–10. A system analysis can show how people, tools, and the environment can combine to produce an accident.

AUDITING

An effective reporting program necessitates complete auditing. Safety personnel should receive a copy of every original work order processed through the maintenance, planning, and cost control center. Safety professionals make on-the-spot checks to see if accidental damage was involved.

SYSTEMS SAFETY

Recently, safety professionals have increasingly been exploring systems approaches to industrial accident prevention. Safety professionals are asked to find ways of implementing systems safety techniques. And although complete system safety analysis requires specially trained engineers and rather sophisticated mathematics, safety professionals find that some knowledge of these techniques can directly benefit them when it comes to codifying and directing their safety and health programs.

Through a system analysis, a safety professional can clarify a complex process by devising a chart or model that provides a comprehensive, overall view of the process, showing its principal elements and the ways in which they are interrelated (Figure 24–10).

Having established the concept of a system, the next step is the analysis of systems. Progress in the analysis of complex systems enables safety professionals to solve problems in accident prevention and the control of occupational illness.

Methods of Analysis

There are four principal methods of analysis: failure mode and effect, fault tree, THERP (technique for human error prediction), and cost-effectiveness. Each has variations, and two or more can be combined in a single analysis.

FAILURE MODE AND EFFECT

In this method the failure or malfunction of each component is considered, including the mode of failure (such as a switch jammed in the on position). The effects of the failure are traced through the system, and the ultimate effect on task performance is evaluated.

FAULT TREE

In this method an undesired event is selected, and all the possible occurrences that can contribute to the event are diagrammed in the form of a tree. The branches of the tree are continued until independent events are reached. Probabilities are determined for the independent events, and, after simplifying the tree, both the probability of the undesired event and the most likely chain of events leading up to it can be computed.

THERP

This is a technique for human error prediction, developed by Scandia Corporation, that provides a means for quantitatively evaluating the contribution of human error to the degradation of product quality. It can be used for human components in systems and thus can be combined either with the failure mode and effect or the fault-tree method.

COST-EFFECTIVENESS

In the cost-effectiveness method, the cost of system changes made to increase safety and health measures is compared with either the decreased costs of fewer serious failures or with the increased effectiveness of the system to perform its task, in order to determine the relative value of these changes. Ultimately, all system changes have to be evaluated, and this method makes such cost comparisons explicit. Moreover, cost-effectiveness analysis is often used to help make decisions concerning the choice of one of several systems that can perform the same task.

In all of these analytical methods, the main point is to measure quantitatively the effects of various failures within a system. In each case, probability theory is an important element.

The systems approach to safety can help to change the safety profession from an art to a science by codifying much of safety and health knowledge. It can help change the application of safety measures from piecemeal problem solving (such as putting a pan under a leak) to a safely designed operation (preventing the leak itself).

The safety professional determines what can happen if a component fails or the effects of malfunction in the various elements of the system, and provides solutions before the accident occurs instead of after the damage has been done.

SAFETY PROFESSIONAL CERTIFICATION

Employers, employees, and the public deserve some assurance that the individuals practicing safety are professionals and are able to provide the safety expertise that, in turn, should provide adequate protection.

Usually, a candidate for professional status must complete a specified course of study, which is followed by practical experience in that field. The applicant must pass an examination to prove mastery of a specific body of knowledge. Finally, a board composed of members of the profession reviews that candidate's qualifications and grants professional certification.

Professional regulation usually results from the need to protect the public from potential harm at the hands of unqualified persons. Clearly, there was a need for professional regulation in the field of industrial safety, and the Board of Certified Safety Professionals was created to fill this need.

The Board of Certified Safety Professionals of the Americas was incorporated in Illinois in 1969 to establish criteria for professional certification, accept applications, evaluate the credentials of candidates, and issue certificates to those who met the requirements.

One method of determining professional abilities is to compare education and experience against a predetermined set of requirements. Once these criteria have been established, each application showing a candidate's education and experience is evaluated against that base. The applicant may be found to be eligible to go to the next step—to take the certification examinations; upon successful completion of the examinations, the candidate is granted certification as a certified safety professional, or CSP.

General Qualifications

To qualify for the *Certified Safety Professional* title one must:

- ➢ apply to the Board of Certified Safety Professionals (BCSP)
- ➢ meet an academic requirement
- ➢ meet a professional safety experience requirement
- ➢ pass the Safety Fundamentals Examination
- ➢ pass the Comprehensive Practice Examination

APPLICATIONS

Details for preparation and application are available at BCSPs web site at www.BCSP.org.

THE ACADEMIC REQUIREMENT

The model educational background for a safety professional and a candidate for the *Certified Safety Professional* is a bachelor's degree in safety from a program accredited by the Accreditation Board for Engineering and Technology.

Because many people enter the safety profession from other educational backgrounds, candidates for the CSP may substitute other degrees plus professional safety experience for an accredited bachelor's degree in safety.

THE EXPERIENCE REQUIREMENT

In addition to the academic requirement, *CSP* candidates must have four years of professional safety experience. The

four years are in addition to any experience used to meet the academic requirement. Professional safety experience must meet all of the following criteria to be considered acceptable by the Board of Certified Safety Professionals:

- ➢ The professional safety function must be the primary function of the position. Collateral duties in safety are not considered the primary function.
- ➢ The position's primary responsibility must be the prevention of harm to people, property, and the environment, rather than responsibility for responding to harmful events.
- ➢ The professional safety function must be at least 50 percent of the position's duties.
- ➢ The position must be full item (defined by BCSP as at least 35 hours per week).
- ➢ The position must be at the professional level. This is determined by evaluating the degree of responsible charge and reliance by peers, employers, or clients on the person's ability to defend analytical approaches used in professional practice and the recommendations made for controlling hazards through engineering and/or administrative approaches.
- ➢ The position must have breadth of duties. This is determined by evaluating the variety of hazards about which a candidate must advise and the range of skills involved in recognizing, evaluating, and controlling hazards. Examples of skills are analysis, synthesis, design, investigation, planning, administration, and communication.

SAFETY FUNDAMENTALS EXAMINATION

The first examination is the Safety Fundamentals Examination. It covers basic knowledge appropriate to professional safety practice. Candidates who meet the academic standard (achieve 48 points through an associate or bachelor's degree plus experience) may sit for the Safety Fundamentals Examination. Upon passing the Safety Fundamentals Examination, candidates receive the *Associate Safety Professional (ASP)* title to denote their progress toward the *CSP*.

Some candidates who have been examined through other acceptable certification and licensing programs and currently hold such certifications or licenses may waive the Safety Fundamentals Examination. The following certifications or licenses are accepted by the Board of Certified Safety Professionals:

- ➢ Certified Industrial Hygienist (CIH) from the American Board of Industrial Hygiene.
- ➢ Certified Health Physicist (CHP) from the American Board of Health Physics.
- ➢ Professional Engineer (PE) from the engineering registration board for any U.S. state or territory.
- ➢ National Diploma in Occupational Safety and Health by the British National Examination Board for Occupational Safety and Health (NEBOSH).
- ➢ Canadian Registered Safety Professional (CRSP) from the Association of Canadian Registered Safety Professionals.
- ➢ Member, Singapore Institute of Safety Officers (SISO).
- ➢ Chartered Engineering (Ceeng) from the Engineering Council (UK).

COMPREHENSIVE PRACTICE EXAMINATION

All CSP candidates must acquire 96 points and pass the second examination, the Comprehensive Practice Examination. To take this examination, a candidate must meet both the academic and experience requirements and have passed or waived the Safety Fundamentals Examination. The total credit for academic degrees at all levels plus the months of professional safety experience must equal or exceed 96 points. After passing the Comprehensive Practice Examination, a candidate receives the *Certified Safety Professional* title.

Once candidates apply for the CSP, they must meet certain time limits as they progress toward the CSP. The section below explains candidate time limit rules. Failure to meet time limits may result in a terminated application. A candidate will then have to reapply and begin the process once again.

CANDIDATE TIME LIMIT RULES

Three-year rules. Three-year time limits apply to several steps in the CSP candidate process.

1. If you are eligible for the Safety Fundamentals Examination, you **must sit for the examination at least every three years**. The three years are computed from the date you become eligible or from the date you last took the examination and failed to achieve a passing score.
2. If you are eligible for the Comprehensive Practice Examination, you **must pass the examination and earn your CSP within three years of becoming eligible**. The Comprehensive Practice Examination eligibility date occurs when you reach 96 points through education and professional safety experience and have either passed or waived the Safety Fundamentals Examination. If you passed the Safety Fundamentals Examination prior to October 1, 1994, you fall under a different rule (contact the BCSP staff).

If you are eligible for the Comprehensive Practice Examination and cannot achieve the CSP before your three-year time limit expires, you may pay a fee and obtain a **one-time, one-year extension** to your time limit.

For more information on the Board of Certified Safety Professionals and the certification process you are encouraged to contact them at:

Board of Certified Safety Professionals
208 Burwash Avenue
Savoy, IL 61874-9571
Phone: (217) 359-2686
Fax: (217) 359-0055
Web Site: www.BCSP.org

THE FUTURE OF SAFETY AS A PROFESSION

Problems, both predictable and unpredictable, can be expected to have an impact on the safety professional in the future. Some of these problems will call for reapplication of established safety techniques. Others will call for radical departures and the creation of new methods and new organi-

zational forms. To be able to discriminate between the two solutions will be, perhaps, the safety professional's greatest test.

The field of occupational safety continues to progress and improve, largely through the continued application of techniques and knowledge that have been slowly and painfully acquired over the years. There appears to be no limit to the progress possible through the application of the universally accepted safety techniques of education, engineering, and enforcement.

Large and serious problems remain unsolved. A number of industries still have high accident rates. There are still far too many instances in which management and labor are not working together or have different goals for the safety program.

Resources available to the safety professional have increased incredibly and with the development of the Internet will do so at an ever-increasing pace. An impressive body of knowledge, a corps of able professional safety people, a high level of prestige, and strong organizations for cooperation and exchange of information will fuel the future for the safety profession.

Well-trained workers are in high demand in practically all phases of safety. Growth in the trade and service industries and the expanding safety needs of educational institutions, construction, transportation, insurance, and governmental groups should further accentuate the demand for safety workers.

Obviously, there is a need in safety work for people with varying degrees of education and experience. The range of opportunities extends from what could be considered paraprofessional to the highly trained and skilled professional at the corporate management level, and includes safety educators and government safety inspectors and researchers.

The safety professional will also need diversified education and training to meet the challenges of the future. Growth in the population, the communication and information explosion, problems of urban areas and future transportation systems, and the increasing complexities of everyday life will create many problems and may extend the safety professional's creativity to the maximum to successfully provide the knowledge and leadership needed to conserve life, health, property, and the environment.

Training of the future safety professional can no longer be limited to the on-the-job experience but must include specialized undergraduate-level training leading to a bachelor's or higher degree. Refresher and continuing education is also necessary and will be just as important in the years ahead.

The type of training needed will depend on the individual job requirements. This presents some difficulties for those preparing to enter the safety and health occupations. Some authorities view the safety and health specialist as a behaviorist and therefore would direct training toward the behavioral sciences, for example, psychology. Others see the specialist as a technician able to handle the technical problems of hazard control, and recommend a heavy background in engineering. Still others believe the safety worker's background should include both the engineering and behavioral aspects.

Future application of this knowledge in all aspects of our civilization—whether to industry or transportation, at home or in recreation—makes it imperative that those in this field be trained to use scientific principles and methods to achieve adequate results. The knowledge, skill, and ability to integrate machines, equipment, and environments with humans and their capabilities will be of prime importance.

SUMMARY

The work of the safety professional follows a pattern. Before taking any steps in the containment of injury, illness, or accidents, the safety professional first identifies and appraises all existing safety and health hazards, both immediate and potential. Once having identified the hazards, the necessary accident-prevention procedures are developed and put into operation. However, this is not enough; safety and health information must be communicated to both management and workers. Finally, the safety professional must evaluate the effectiveness of safety and health control measures after they have been put into practice. If conditions warrant, the safety professional can recommend changes in materials or operational procedures or, possibly, that additional enclosures or safety equipment be added to existing machinery.

Accurate records are essential in the search for the cause of an illness or an accident, and can aid in finding the means to prevent future similar incidents. When studying records to determine the cause or causes of accidents, the records of other companies with similar operations should not be overlooked. Upon determining the cause, the safety professional will have a firm basis on which to propose preventive measures.

Preventive measures are obviously better than corrective measures taken only after an accident has occurred. This means that one of the most valuable functions of the safety professional is to examine the specifications for materials, job procedures, new machinery and equipment, and new structures from the standpoint of safety and health well before installation or construction. In some cases, the safety professional can even help draft the necessary specifications.

As part of the overall safety and health program, the safety professional should recommend policies, codes, safety standards, and procedures that should become part of the operational policies of the organization.

The safety professional draws on specialized knowledge in both the physical and social sciences and applies the principles of measurement and analysis to evaluate safety performance. The safety professional should have a fundamental knowledge of statistics, mathematics, physics, chemistry, industrial hygiene, environmental sciences, and engineering.

The safety professional should be a well-informed specialist who coordinates the safety and health program and supplies the

ideas and inspiration while enlisting the wholehearted support of management, supervision, and workers.

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Chapter 25

The Occupational Medicine Physician

by Linda H. Morse, MD, FACOEM

Occupational medicine is a field that has changed dramatically over the past 50 years in composition, focus, and scope. The new millennium offers continuing new challenges, including the hazards and opportunities of practice outside our planet's atmosphere. Critical to meeting those challenges is a team effort focusing on identification and prevention of workplace hazards, working closely with industrial hygiene and occupational health nursing. Partnership with government, industry, and labor scientists in evaluation of the five classes of hazards faced in industrial operations daily—chemical, biological, physical, stress/shiftwork, and ergonomic—must be an ongoing task. We also must jointly maintain a clear ethical focus in our work, as the economic and organizational pressures are strong to look at fiscally productive solutions without always keeping employee health and safety primary. For the industrial hygienist or safety professional seeking partnership with occupational medicine physicians, some understanding of the history of the field in the United States is important.

HISTORY

From very early days physicians have noted the importance of occupation in the causation of disease and injury. Bernardino Ramazzini in 1713 described the diseases that afflict scribes and notaries in a supplement to his *De Morbis Artificum (Diseases of Workers)*—a classic portrayal of our current upper extremity cumulative trauma disorders:

> *"The maladies that afflict the clerks aforesaid arise from three causes: First, constant sitting; secondly, the incessant movement of the hand and always in the same direction; thirdly, the strain on the mind from the effort not to disfigure the books by errors or cause loss to their employers when they add, subtract or do their sums in arithmetic.…In a word, they lack the benefits of moderate*

> *exercise, for even if they wanted to take exercise, they have no time for it; they are working for wages and must stick to their writing all day long. Furthermore, incessant driving of the pen over paper causes intense fatigue of the hand and whole arm because of the continuous and almost tonic strain on the muscles and tendons, which in the course of time results in failure of power in the right hand." (Herington & Morse, 1995)*

During the 1700s to 1800s in the United States, medicine itself was undergoing rapid change. Before 1900 many "doctors" had no formal training, and practiced a variety of healing arts and techniques, few based on science. Medical training was not standardized and licensing of medical professionals was "lax." During the late 1800s however state licensing laws were passed requiring a degree from a medical school and passing a formal examination. The American Medical Association (AMA), initiated in 1846, became a powerful force over the next 50 years, setting standards for medical education. In 1904 the AMA set up the Council on Medical Education, which began "grading" medical schools. In 1910 the council's Flexner Report was harshly critical of the country's 131 medical schools, recommending closure of 99 of them, although eventually 70 survived (Kaiser Permanente, 1995).

Scientific breakthroughs in the late 1800s spurred much of this change. Use of anesthesia, aseptic technique, development of diagnostic instruments such as the stethoscope and ophthalmoscope, tests such as x-rays and electrocardiograms, identification of organisms causing diseases such as cholera and tuberculosis and development of vaccines for use against them, combined with standardized population-based tests for vision, height/weight, and IQ, all contributed to "the scientific practice of medicine"(Kaiser Permanente, 1995). Hospitals, previously considered dangerous disease-ridden places to die, became centers of the new practice of medicine.

Simultaneously, the United States was moving from an agricultural society to an industrial one. Beginning in the 1860s, railroads and mining companies began employing physicians, paying them through payroll deductions or salaries. The organization doctor was hired to treat victims of industrial accidents, keeping them working and hopefully preventing lawsuits. Workers' compensation laws did not exist until the early 1900s, when states began adopting laws set-ing up no-fault compensation systems to both care for the injured workers and confine benefits within a no-fault sysem, preventing legal action (Kaiser Permanente, 1995).

Company doctors treated injuries, performed medical examinations, and often provided nonindustrial care to workers' families, especially in remote areas. They were sometimes viewed with suspicion by not only the workers, but also other medical practitioners. In 1908, a Sears Robuck physician resigned his position because he was excluded from membership in the Chicago Medical Society on the grounds that his reduced-rate services, provided to employees' families, constituted " an unethical invasion of private practice"(Kaiser Permanente, 1995).

The American Association of Industrial Physicians (later renamed the American Occupational Medicine Association [AOMA]) was founded in 1916, and focused mostly on physical examinations and dealing with physical trauma. The American Academy of Occupational Medicine (AAOM) was founded in 1946, with membership limited to physicians who devoted full time to the field of occupational medicine (Goldwater, 1973; Welter, 1988). These physicians were concerned about preventing injury and illness, especially from toxic exposures. The American Board of Preventive Medicine was established two years later, and in 1956 was reorganized into three parts: Public Health, Aviation Medicine (now Aerospace Medicine), and Occupational Medicine. This provided an avenue for Board Certification as a specialist in this field for the first time.

Most of the focus was still on the corporate occupational medicine department during the next two decades, and the membership in the AAOM and the AOMA (later to merge into one group, the American College of Occupational Medicine) remained composed primarily of organization-based physicians. However, occupational health hazards were growing; the post World War II industrial boom brought thousands of new chemicals into existence for which neither human beings nor our Earth's ecology had developed any evolutionary defenses. Even asbestos, silica, and other compounds, which are naturally part of our planet, were being transformed into new products, with exposures causing epidemics of disease among workers in mining and production operations. Growing public concern about these problems, combined with the civil rights and antiwar activism of the 1960s and 1970s spread into the issue of occupational exposures, with unions and community organizers forming local Committees on Occupational Health and Safety (COSH) groups across the country. Many of the physicians in the COSH groups joined the American Public Health Association Occupational Health Section, partly because of organizational political views and because all members of the occupational health team including nurses, industrial hygienists, and safety personnel, could be members of the same organization.

In 1970 the Occupational Safety and Health Act was passed by Congress, mandating a safe and healthy workplace for all employees. With passage of this legislation came significant additional resources for industrial hygiene and occupational health nursing programs and development of new physician training programs in occupational medicine, previously limited to a very few corporate and academic centers.

Meanwhile, occupational medicine has grown as a field, encompassing environmental issues as well. The ACOM transformed into the American College of Occupational and Environmental Medicine (ACOEM). Twenty-six occupational medicine residency programs exist at major universities across the United States, graduating approximately 75

physicians per year, a figure which unfortunately is barely keeping up with those retiring or otherwise leaving the field. Over 7,000 doctors are members of ACOEM; approximately 1,500 of them board-certified as specialists.

The practice of occupational medicine has also changed dramatically within the last three decades since the OSHAct was passed. Corporate downsizing and contracting out has resulted in the demise of the corporate medical department in many companies, although it still exists. Work with or for unions grew out of the COSH group model of the 1970s and provides a focus for some occupational health professionals, with the more recent environmental activism also attracting full time or volunteer occupational and environmental health physicians. Occupational medicine is now a sub-specialty of the medicine division or its own department in many large medical group practices, hospitals, and universities. Freestanding occupational health clinics, often combined with urgent-care centers, offer another practice setting. Private consulting firms and international work are two growing sectors of occupational medicine practice. Academic, occupational, and environmental health departments are a major development since the 1970s and offer clinical and other research opportunities, all of which will be discussed in the following sections. It is important for the industrial hygiene or safety professional working with the occupational medicine physician to understand the background, training, and ethical focus not only of the individual physician, but also the organizational context within which the doctor is working.

CREDENTIALS AND PROFESSIONAL ASSOCIATIONS

All physicians graduating medical school after 1984 are required to take a formal occupational medicine residency or fellowship program in order to become eligible to take the Occupational Medicine Board Examination. The program encompasses two years, usually after a full or partial residency in another field, such as internal medicine. The program content includes significant public health training in toxicology, epidemiology, and statistics (usually leading to a Masters in Public Health), and a practicum year of clinical, research, and corporate placements, and public sector agency rotations. Most of the academic occupational medicine residency programs have a very heavy focus on toxicology and epidemiology. More recently, increased interest in cumulative trauma disorders has led to research and clinical work on musculoskeletal injuries in a number of centers.

Physicians graduating medical schools before 1984 can "grandfather" in and become board-eligible in occupational medicine by working in the field full time for five years, taking core public health courses, and obtaining reference letters from three physicians, two of whom must be certified in occupational medicine.

Because many physicians become interested in occupational medicine after practicing in another field for several years (and thus acquiring financial and family obligations which make it difficult to go back to a fellowship salary and schedule), recent developments including online coursework through the Internet can lead to the MPH degree. There is also significant interest in creation of part time residency programs and alternative credentialing for occupational health physicians, as the current process is not producing enough qualified practitioners to meet the needs of the country.

The Occupational Medicine Board Examination is a lengthy test which is offered only annually by the American Board of Preventive Medicine. Applicants must demonstrate proficiency in both preventive medicine and occupational medicine in order to pass. Approximately 200–300 physicians take the examination annually.

Professional associations include the American College of Occupational and Environmental Medicine, which has approximately 6,000 members in the United States, Canada, and Mexico. Fellowship in ACOEM is conferred only upon those who are board-certified. This organization has changed significantly since the 1970s, now including physicians from a wide variety of practice settings. ACOEM publishes a monthly journal, *The Journal of Occupational and Environmental Medicine,* which has significantly improved its scientific standards. The American Public Health Association (APHA) has a very active Occupational Health Section, composed not only of physicians but also nurses, industrial hygienists, epidemiologists, and others in the field. It publishes articles in the *APHA Journal* and a section newsletter. The National Association of Occupational Health Professionals was created to provide a venue for occupational health professionals from all fields to develop their skills in marketing, managing clinics, and other difficult administrative issues.

PRACTICE SETTINGS

Corporate Medical Department

As indicated previously, this area of occupational medical practice is shrinking, due to organizations downsizing and contracting out. The days of the corporate medical director overseeing a large staff of physicians and nurses providing preplacement and periodic surveillance exams, executive physicals, acute work-related injury/illness treatment, and on-site wellness and nonindustrial acute medical care are largely, although not entirely, gone. However, controversy still exists over whether or not this development is truly cost effective in the long run (Anstadt, 1994; Hathaway, 1994). The corporate medical director today is likely to be a consultant to human resources, helping provide quality assurance over the contract clinics which actually provide the services, and aiding in review and negotiation with health plans, medical review for difficult workers' compensation cases, ADA,

and fitness-for-duty issues, development of protocols for exposures, and medical surveillance. Increasingly important in today's world is the issue of international travel and exposures of employees to infectious diseases; physicians working for multinational corporations have to become experts in travel medicine (Fletcher & Freeman, 1994). Most often, board certification in occupational medicine is required (frequently combined with board certification in another field such as internal medicine), along with significant business/financial acumen and experience.

Multispecialty Group Practice/ Hospital-Based Programs

This sector has been a growing source of practice opportunities for occupational medicine physicians. The physician may work in a separate occupational medicine department or as a subspecialist, usually in a division of medicine or family practice, sometimes as part of emergency/urgent care. Usually these positions are primarily clinical, and frequently require a heavy patient load of 20 to 30 patients per day. Additional responsibilities may include developing programs to attract local industry (e.g., injury care, preplacement examinations, drug testing), performing consults for colleagues from other departments/divisions on work or disability issues, and helping to ensure that workers' compensation visits are correctly reported and billed. Advertisements for these jobs increasingly request board certification in occupational medicine. Due to the shortage of certified specialists, however, they are frequently filled by physicians certified in other specialties (internal medicine, emergency medicine, family practice) who have transitioned to occupational medicine for a variety of reasons.

Freestanding Occupational Health Clinics

These clinics may be a single entity or part of a chain of clinics, located near industry, and developed to serve multiple local companies by providing a range of services from preplacement examinations and drug testing to acute care for work related injuries and illnesses. Sometimes the industrial services are combined with urgent care for nonindustrial problems and even a travel medicine service. These clinics do not usually have the access to specialized services that hospital or multispecialty group practice programs have. Often practitioners in these clinics are required to see 30 or more patients per day. Doctors working in these clinics may not be specialists in the field, and focus on injury illness treatment and preplacement and surveillance examinations. Mostly, physicians working in these clinics will have little time or training to deal with complex health and safety issues. (Leone & Schumman, 1995).

Private Consulting Firms

Many academically trained, board-certified occupational medicine physicians chose to join or set up their own consulting firms. This allows a wide range of practice opportunities, including consulting with companies, local government agencies, and unions, performing medical surveillance and other examinations, acting as expert witnesses, and doing epidemiological research. Frequently these firms have close working relationships with industrial hygienists, epidemiologists, toxicologists, and occupational health nurses, or have them on staff.

Academic Occupational Medicine Departments

These have been established in all of the universities with occupational medicine residency programs and many others, and are growing in number. Responsibilities in this setting include research and teaching as well as patient care, consulting, and expert witness testimony. Occupational Medicine physicians working in academic settings are board-certified, frequently in occupational medicine and another specialty. These positions may also require responsibilities related to the other specialty in addition to occupational medicine.

Government Agencies

Policy development and regulatory agencies in the areas of occupational and environmental health and safety will often have one or more staff physicians, usually board-certified, to provide scientific oversight and back-up. These physicians are rarely involved in clinical work with patients, but function in consultation, advising on epidemiological, toxicological, and other issues; and often helping to perform epidemiological studies in response to public health or regulatory need. NIOSH, OSHA, state OSHA programs, EPA, and many other governmental agencies on federal, state and local levels have well-trained and credentialed occupational and environmental physicians who can be a significant resource to industrial hygiene and safety personnel. The branches of the military also have active occupational medicine programs for which they send physicians to occupational medicine residency programs in exchange for a certain number of years of service in the armed forces in the future.

International Occupational Health Consulting

This a is a growing, much-needed arena attracting a number of board-certified occupational medicine physicians. The rapid industrialization of sectors in Asia, South America, and some parts of Africa, combined with the breakup of the Soviet Union, has resulted in significant industrial and environmental problems without the governmental, academic, or private sector infrastructure or expertise to deal with them. Occupational health and safety professionals from the United States, Canada, and Western Europe are sought eagerly for consultation with duties ranging from training of local professionals, development and carrying out epidemiological research studies, governmental policy and legislative consultation, and presentations at international conferences.

Union Occupational Health Physicians

Since the 1970s unions have developed relationships with occupational medicine physicians, industrial hygienists, and epidemiologists. Some, such as the Oil Chemical and Atomic Workers, International Association of Firefighters, and the United Auto Workers have had full time staff personnel. Others have formal or informal consultant relationships or medical advisory boards. Occupational health and safety has been an important issue for members of unions exposed to significant chemical hazards in the past, and is a growing issue for newer service sector unions, such as Service Employees International Union and the Transport Workers Union, concerned about back injuries, cumulative trauma disorders, and protection from violence on the job. Union efforts have been key in legislative passage of stronger workplace health and safety regulations, and professional medical expertise is critical for creation and support of this legislation.

SCOPE OF PRACTICE

Industrial hygiene and safety professionals seeking to work with the occupational medicine physician should have an understanding of the skill and interest level of the particular doctor or organization. An informal meeting, preferably at the clinician's office with a request for a curriculum vitae, will provide significant information about his/her level of training and background. A discussion of an exposure problem, a case that poses ethical issues, queries about what texts or databases the physician would use to answer a question, are all productive avenues to explore when considering setting up a professional relationship.

Physicians working in the field of occupational medicine should minimally be familiar with the state and federal workers' compensation systems, be able to evaluate and treat common work related injuries and illnesses (including determining industrial causation), and be able to perform preplacement, Department of Transportation (DOT), and basic medical surveillance examinations for respiratory protection, asbestos, or lead exposure. Most nonboard-certified occupational health physicians will not necessarily be competent on issues of toxic chemical exposure, physical hazards, biological hazards (except for bloodborne pathogens), stress/shiftwork issues, or difficult ergonomic problems except perhaps office ergonomics. They should be familiar with other occupational medicine resources in the community and be able to guide the safety/industrial hygiene professional to those who have the expertise to deal with more complicated issues.

Board-certified occupational medicine physicians, especially those academically trained, should be able to provide expertise and guidance on the more complicated toxic and other workplace hazards, including the especially difficult issues of causation, because of their training in toxicology, epidemiology, and critical review of the medical literature. They should also be familiar with important legislative developments both local and national, including employment and health and safety-related issues, such as the Americans with Disabilities Act, status of upcoming bills on hot topics such as ergonomics, changes in workers' compensation laws, and legislation about medical surveillance requirements. Protocol and policy development group medical screenings, presentations to employers and employees, and complicated fitness-for-duty evaluations should also be part of their areas of competence. Additionally they should be able to help in policy development, and create medical protocols for surveillance examinations. Many have additional specialized credentials as disability evaluators, Medical Review Officers (MRO) for drug screening programs, or aviation medical examinations.

Specialty consultant firms or physicians working for environmental groups, academic occupational medicine departments, or governmental experts from national, state, or local agencies should be sought for significant environmental hazard issues, as these are usually far more complicated than industrial exposure problems. Similarly, these professionals are best able to provide expert-witness testimony or create designs for epidemiological studies for either occupational or environmental hazards.

THE OCCUPATIONAL HEALTH HISTORY

A brief occupational health history should be part of all medical histories as occupational hazards can be a cause of almost any adult disease or injury. Carpal tunnel syndrome used to be considered a problem of aging women, or *idiopathic*—something for which medicine has no explanation. Now we know a significant percentage of cases are caused by work factors. Coronary artery disease can be caused by exposure to carbon disulfide in rayon manufacturing, and Parkinson's disease, a serious neurological disorder, is not only caused by manganese exposure in mining operations but also some synthetic chemicals, used both in industry and in street drugs. Since most adults spend almost one third of their time at work, consideration of their work exposures is an important part of modern medicine.

Unfortunately, most physicians are still not appropriately trained in taking a good occupational history. In four years of medical school, there is an average of four hours spent on occupational exposures—in the schools that teach any at all. Thus the safety and health professional must rely on referral to specialists in the field. An excellent sample occupational history form is included in this chapter (see Figure 25–1). It is easily reproduced, and easily filled out by most employees. The worker should be instructed to fill out the form chronologically, starting with current job and working backwards, or beginning with work done in grade or high school and working forward to the current job. This format allows the employee to be as complete as possible without the burden of being asked dozens of questions about chemicals and processes which she or she is unfamiliar.

OCCUPATIONAL HISTORY FORM
PART I

Name _____

Please answer the following work history questions. Begin with your first job in school (i.e. paperboy) and list all jobs held in order after that.

**For those in building trades it may be difficult or impossible to remember every job. Please try to list all those where you worked a long time or had toxic exposure or illness. (use back of sheet if necessary)

COMPANY NAME OR SELF-EMPLOYED City, state (include any military service)	DATES From Mo/Yr	DATES To Mo/Yr	GIVE JOB TITLE or major activities	LIST POTENTIAL HAZARDS EXPOSED TO **Physical** (Noise, radiation, vibration, electrical shock, temperature extremes, etc.)	**Chemical** (Mercury, lead, gases, fumes, acids, solvents, caustics, fly ash, dust, etc.)	**Biological** (Viruses, bacteria, parasites, fungus, animal bites, etc.)	**Psychological** (Boredom, workshift fatigue, risk of falling or being buried, repetitive tasks, etc.)	PERSONAL PROTECTIVE EQUIPMENT WORN ON THE JOB (Hard hats, respirators, ear plugs, gloves, aprons, goggles, safety shoes, etc.) List for each job

Figure 25–1. Occupational History Form. *(Continues)*

OCCUPATIONAL HISTORY FORM
PART II

I If you have had any secondary work such as firefighting, civil defense, farming, gardening, please list.
Type of work Dates

II List hobbies and active sports you do (past and present) such as painting, woodworking, welding, hairdressing, scuba diving, etc.

III Please comment on any work-related experiences you have had that you believe may have been harmful to your health.

IV Have you or your present or former spouse had any adverse reproductive outcome? If so, please indicate circumstances (e.g., stillborn, deformed, miscarriage, infertility, irregular menses, etc.)

Figure 25–1. Occupational History Form. *(Concluded)*

With this history form, for example, a 38-year-old commercial plumber who was referred for evaluation of acute onset of leukemia and who had worked in the pipe trades "all my life," was identified as having significant benzene exposure because he noted a six-month stint at a tire manufacturing plant before he became a union apprentice. He did not know what benzene was, and would have answered negatively if questioned just about the chemical.

In addition to past and current occupational history, with exposure and protective equipment notations, the form also covers moonlighting jobs and hobbies. Often the significant exposures are found here, as opposed to the full-time occupation. Finally, questions about reproductive history are also an important part of the occupational history, as effects from certain chemicals and other hazards may present first or only in this arena.

When evaluating a specific job, in addition to the questions reviewed previously, a special focus on three components may be useful. Specific questions about the workstation and work tools, work tasks, and the individual's work practices are helpful in eliciting information that can lead to needed corrective measures to prevent or resolve injury or illness, especially for ergonomic problems or indoor air quality problems.

The occupational history needs review by a specialist with a good library and Internet search capacity so that specific occupations and exposures can be cross-referenced against the injury or illness of concern.

THE PREPLACEMENT EXAMINATION

Preplacement examinations are an important part of ensuring a safe and healthy workforce, as hiring those physically unable to do the job tasks places an added burden and risk of injury on coworkers. Legislative changes and court rulings over recent decades have appropriately limited employers' ability to arbitrarily deny jobs based on criteria unrelated to the actual job requirements; and many employers decided that there was no point to spending money doing preplacement examinations if there was nothing they could do with the information.

Preplacement evaluations can range from a simple drug screen, a medical history review by a registered nurse to a complete medical and occupational history and physical examination with functional capacity testing and other tests. There are some occupations for which a thorough evaluation is appropriate. The physical, chemical, and other hazards found in firefighting, hazardous waste work, and certain other job classes warrant complete histories and physicals, and cardiac, pulmonary, and strength/endurance testing.

For most job classifications, however, extensive testing is unwarranted and has not been found to reduce workers' compensation or nonindustrial illness absenteeism costs. If preplacement testing is contemplated, it should be targeted to the job requirements and can also be oriented to provide a baseline for injuries/illnesses that have high compensation costs for the employer. Even without functional capacity testing, a thorough neuromuscular evaluation will identify any preexisting abnormalities of upper trapezius spasm, or a reflex deficit from a prior back disc injury. *Jamar dynamometer grip strength testing* is advised as part of this process, as it readily identifies those with grip strength below expected, and thus at increased risk of both acute and cumulative trauma upper extremity injuries. Those found deconditioned or lacking flexibility or strength can be counseled and given specific exercises to correct the problem before an injury occurs.

Similarly in jobs where there is possible irritant chemical exposure, careful evaluation of the skin, mucous membranes, and eye conjunctivae (for cobblestoning) as well as a lung exam and possibly simple screening spirometry allow counseling of those with allergic problems not well controlled and establishes a baseline.

Even simple preplacement medical screens usually involve a blood pressure and vision check and sometimes urinalysis. These can be valuable in detecting non-industrial diseases like hypertension and diabetes, which need medical intervention for the health of the employee. Referrals should be made in writing on identification of new or uncontrolled problems and a copy kept in the record for documentation that a referral back to the patient's primary-care physician was made. These efforts increase the employee's perception of the organization's attitude toward workers' welfare in addition to sometimes catching and treating disease early.

Care must be taken by the examining clinician to avoid making hiring decisions. The role of the medical evaluation is to determine fitness for duty, and it is the organization that decides whether or not the person can be accommodated, not the clinician. The clinician describes any needed accommodations without revealing the medical problem requiring them on a simple work slip given to the employer. Even with a release of information signed by the employee, it is important to avoid revealing confidential personal medical information (e.g., about diabetes or HIV status) to nonmedical personnel.

Industrial hygiene, safety, and environmental professionals can help employers identify medical providers who will provide cost-effective and ethical preplacement evaluation services that promote employee wellness.

SUMMARY

Occupational medicine physicians are an essential part of the health, safety, and environmental team, no matter what the setting. Physicians who strive for the practice of ethical, cost-effective, scientifically based occupational medicine and who recognize the importance of teamwork and the equally essential roles of nursing, industrial hygiene, environmental, and safety professionals are increasingly available.

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Chapter

26

The Occupational Health Nurse

by Barbara J. Burgel, RN, MS, COHN-S, FAAN

Occupational health nursing has an important historical role in protecting the health of workers. Occupational health nurses have made over 100 years of solid contributions in this public health discipline, and are committed to working with employees and their dependents, employers, and other health and safety team members to attain a safe and healthy workplace.

Not only is the occupational health nurse (OHN) instrumental in managing health and safety programs in the worksite, but the OHN provides the critical link between employee health status, the work process, and the determination of employee ability to do the job. Knowledge of health and safety regulations, workplace hazards, direct care skills, counseling, teaching, and program management are but a few of the key knowledge areas of the OHN, with strong communication skills of utmost importance. Knowledge of cost control strategies, in this era of rising direct and indirect health care costs, is a critical OHN skill.

OBJECTIVES

This chapter provides:

- An overview of the professional aspects of the OHN role, including standards of practice and certification.
- A model of occupational health nursing, including a discussion of competencies needed for professional practice activities.
- Examples of primary, secondary, and tertiary prevention programmatic activities by occupational health nurses in the worksite.

OVERVIEW

Definition of the Occupational Health Nurse

Over 23,000 registered nurses provide care to employees with the goal to prevent work-related injury and illness, prevent disability, and help workers achieve and maintain the highest level of health throughout their lives. Occupational health nurses maintain a focus on the worksite where they deliver quality care, and philosophically support a primary prevention-based practice. If injuries do occur, a case management approach is utilized to return injured employees back to appropriate work in a timely basis, and this "case" provides an additional opportunity for worksite prevention. The American Association of Occupational Health Nurses (AAOHN) maintains, and many industries have found, that "The nurse is key to the coordination of a holistic, multidisciplinary approach to delivery of safe, quality, and comprehensive occupational health and safety services" (AAOHN, 1999, p.3).

Occupational and environmental health nursing is the specialty practice that provides for and delivers health and safety services to employees, employee populations, and community groups (AAOHN, 1999). The practice of occupational health nursing is grounded in the public health principles of primary, secondary, and tertiary prevention, and is focused on promotion and the restoration of health, prevention of illness and injury, and protection from occupational and environmental hazards. (AAOHN, 1999, p.2).

Scope of Practice

The OHN is licensed as a registered nurse, and has both independent and dependent nursing functions, as authorized by the state business and professions code. Advanced practice nursing roles are also licensed state by state, and include those registered nurses prepared at the graduate degree level in the roles of clinical specialist, nurse practitioner, nurse midwife, and nurse anesthetist (AACN, 1994). OHNs use the nursing decision-making process, including collecting subjective and objective data, making assessments and plans, and going through an evaluation, and are responsible to maintain competence, and practice within a legal and ethical framework of professional practice. Occupational health nursing services include:

- ➢ Clinical and primary care including assessment, diagnosis, management, and documentation of occupational and nonoccupational illness and injury
- ➢ Case management for occupational and non-occupational illness and injury
- ➢ Health hazard assessment and surveillance of employee populations, workplaces, and community groups
- ➢ Investigation, monitoring, and analysis of illness and injury episodes and trends, as well as methods to promote and protect employee health and safety
- ➢ Compliance with laws, regulations, and standards governing health and safety for employees and the environment
- ➢ Management and administration of occupational and environmental health services
- ➢ Health promotion and disease prevention strategies using primary, secondary, and tertiary principles
- ➢ Counseling, health education, and training programs using adult learning approaches
- ➢ Research related to occupational and environmental health (AAOHN, 1999)

Figure 26–1 is one model of occupational health nursing, recognizing internal and external forces impacting the range of OHN services (Rogers, 1994). These internal and external forces include the dynamic sociocultural, economic, political, and technological factors affecting work, for example, the aging workforce, the amount of resources dedicated to the prevention of work-related injuries, new OSHA standards or disability regulation, and the introduction of new technology into a new work process.

STANDARDS OF PRACTICE FOR OCCUPATIONAL AND ENVIRONMENTAL HEALTH NURSING

Standards of Occupational and Environmental Health Nursing Practice, developed by AAOHN (1999), enable the profession to insure a quality-based practice, and to provide protection to the consumer and the profession alike. A summary of the standards include:

Standard I: Assessment—The occupational and environmental health nurse systematically assesses the health status of the individual client or population and the environment.

Standard II: Diagnosis—The occupational and environmental health nurse analyzes assessment data to formulate diagnoses.

Standard III: Outcome Identification—The occupational and environmental health nurse identifies outcomes specific to the client.

Standard IV: Planning—The occupational and environmental health nurse develops a goal-directed plan that is comprehensive and formulates interventions to attain expected outcomes.

Standard V: Implementation—The occupational and environmental health nurse implements interventions to attain desired outcomes identified in the plan.

Standard VI: Evaluation—The occupational and environmental health nurse systematically and continuously evaluates responses to interventions and progress toward achievement of desired outcomes.

Standard VII: Resource Management—The occupational and environmental health nurse secures and manages the resources that support an occupational health and safety program (Figure 26–2).

Standard VIII: Professional Development—The occupational and environmental health nurse assumes accountability for professional development to enhance professional growth and maintain competency.

Standard IX: Collaboration—The occupational and environmental health nurse collaborates with employees, management,

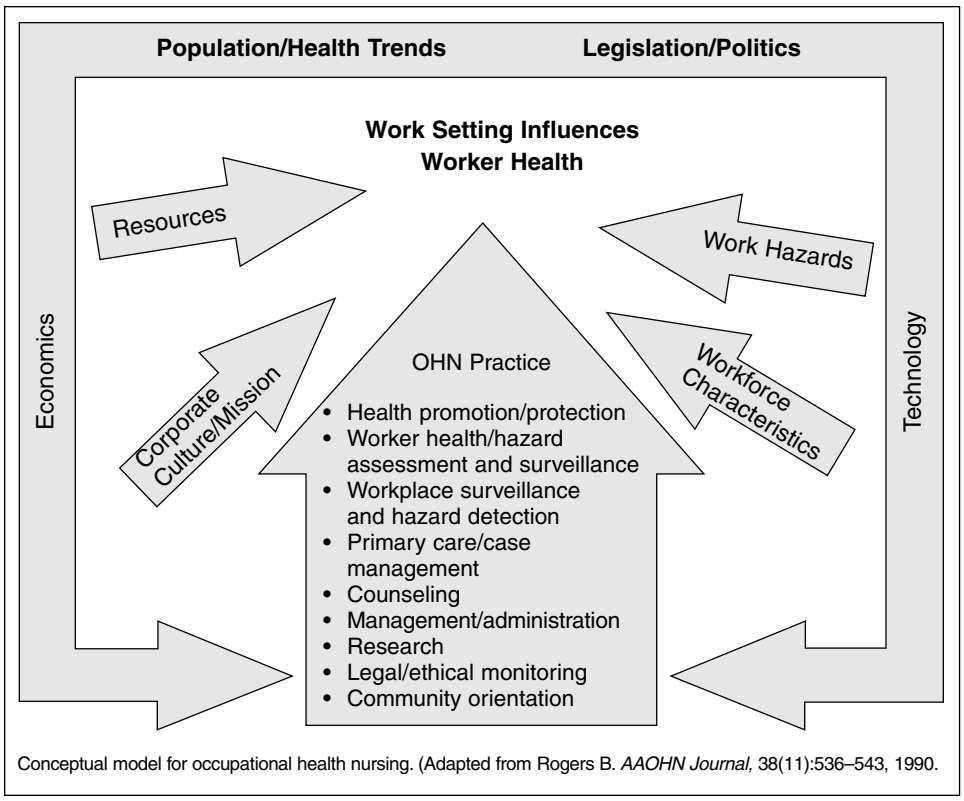


Figure 26–1. One model of occupational health nursing, recognizing internal and external forces impacting the range of OHN services (Rogers, 1994).

other health care providers, professionals, and community representatives.

Standard X: Research—The occupational and environmental health nurse uses research findings in practice and contributes to the scientific base in occupational and environmental health nursing to improve practice and advance the profession.

Standard XI: Ethics—The occupational and environmental health nurse uses an ethical framework as a guide for decision making in practice. (AAOHN, 1999)

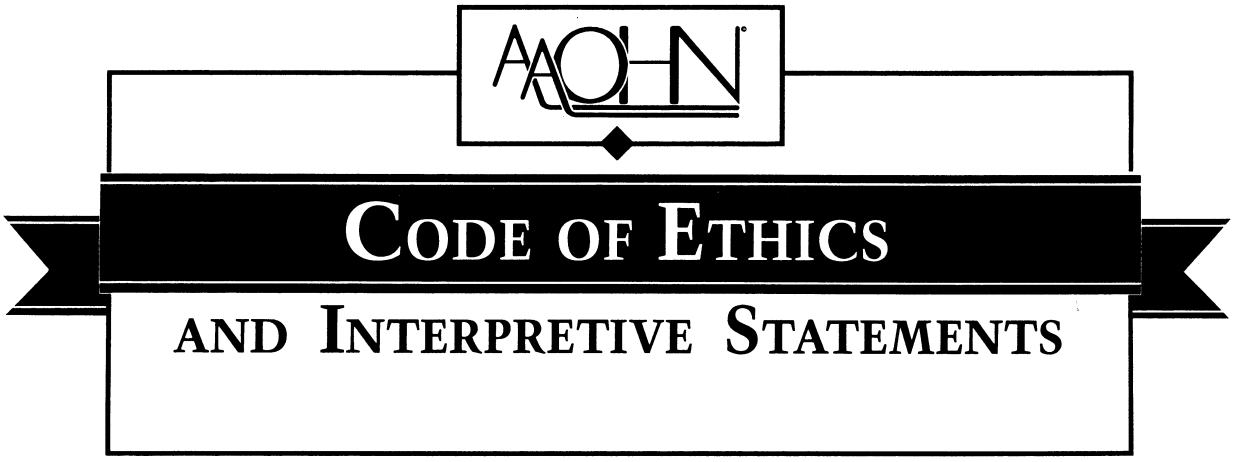
PROFESSIONAL MEMBERSHIP AND CERTIFICATION

More than 12,000 OHNs are members of the professional specialty nursing organization, the American Association of Occupational Health Nurses (AAOHN). AAOHN established a Code of Ethics and Interpretive Statements (Table 26–A), and a position statement and guidelines on Confidentiality of Health Information (Table 26–B).

More than 6,000 OHNs have been recognized for excellence in occupational health nursing practice through certification by the American Board for Occupational Health Nurses, Inc. (ABOHN, 2000). The Certified Occupational Health Nurse (COHN) and the Certified Occupational Health Nurse Specialist (COHN-S) credentials are awarded based on specific educational preparation, current occupational health work experience, evidence of continuing occupational health and safety education, and successful

Figure 26–2. The occupational and environmental health nurse secures and manages the resources that support an occupational health and safety program.

Table 26–A. *AAOHN Code of Ethics*



Preamble

The American Association of Occupational Health Nurses, Inc. (AAOHN) Code of Ethics has been developed in response to the nursing profession's acceptance of its goals and values and the trust conferred upon it by society to guide the conduct and practices of the profession. As professionals, occupational and environmental health nurses accept the responsibility and inherent obligation to uphold these values.

The Code of Ethics is based on the belief that the goal of occupational and environmental health nurses is to promote worker health and safety. This specialized practice is devoted to health promotion, prevention, and management of illness and injury at the worksite. The client can be both an individual worker or an aggregate worker population. The purpose of the AAOHN Code of Ethics is to serve as a guide for registered professional nurses to maintain and pursue professionally recognized ethical behavior in providing occupational and environmental health services.

Ethics is synonymous with moral reasoning. Ethics is not law, but a guide for moral action. Universal moral principles are utilized by professional nurses when making judgements related to the health and welfare of the worker or worker population.

The most significant principle for occupational and environmental health nurses is autonomy, or the right to self-determination, which encompasses respect for an individual's right to privacy and refusal of care. Confidentiality and truth-telling are related concepts. Other key principles are beneficence (doing or producing good); nonmaleficence (avoiding harm); and justice (fair and nondiscriminatory treatment of all individuals).

Occupational and environmental health nurses recognize that dilemmas may develop that do not have guidelines, data, or statutes to assist with problem resolution; thus, occupational and environmental health nurses may use problem-solving, collaboration, and appropriate resources to resolve dilemmas.

The Code is not intended to establish nor replace standards of care or minimal levels of practice. In summary, the Code of Ethics and Interpretive Statements provide a guiding ethical framework for decision-making and evaluation of nursing actions as occupational and environmental health nurses fulfill their professional responsibilities to society and the profession.

Table 26–A. *AAOHN Code of Ethics (continued)*

1. Occupational and environmental health nurses provide healthcare in the work environment with regard for human dignity and client rights, unrestricted by considerations of social or economic status, personal attributes, or the nature of the health status.

The profession of occupational and environmental health nursing is dedicated to the promotion, protection, and preservation of the life and health of every client. Occupational and environmental health nurses render nonprejudicial and nondiscriminatory care to clients.

Occupational and environmental health nurses have an obligation to treat clients fairly, respecting their dignity and worth. While recognizing the existence of a vast diversity of cultural beliefs and values in society, occupational and environmental health nurses demonstrate respect for these beliefs and values inherent in their clients and themselves and plan health care services for and with that client accordingly.

Occupational and environmental health nurses respect their clients' rights to autonomy. Clients are encouraged to participate in planning their own healthcare, and occupational and environmental health nurses are truthful in providing clients with necessary information to make an informed judgement. While respecting their clients' interests and well-being, nurses examine the short-term and long-term outcomes of the decision-making process. As clients advocate, occupational and environmental health nurses have the responsibility to be knowledgeable about their clients' rights. These rights include acceptance or refusal of care and are acknowledged by professional nurses. When personal convictions of occupational and environmental health nurses prohibit participation in providing health services and/or when clients refuses care, the nurses may not be exempt from protecting their clients' health and safety. Occupational and environmental health nurses avoid abandonment and refer clients to available, alternative sources of care.

2. Occupational and environmental health nurses promote collaboration with other health professionals and community health agencies in order to meet the health needs of the workforce.

Occupational and environmental health nurses are members of the occupational and environmental health and safety team. Occupational and environmental health nurses function both interdependently and independently in promoting the welfare of clients. Providing health services to clients requires a commitment to collaborative planning with other health professionals and members of the occupational and environmental health team. Occupational and environmental health nurses make referrals to appropriate community resources and seek assistance and expertise from other recognized health professionals in the provision of services, as appropriate. Occupational and environmental health nurses function within the scope of nursing practice and delegate responsibility to members of the health and safety team as necessary. Occupational and environmental health nurses have an obligation to promote adequate distribution of healthcare and nursing resources to meet clients' needs. Occupational and environmental health nurses are responsible to management as employees. As professionals, occupational and environmental health nurses are advocates for the workers. Occupational and environmental health nurses recognize situations in which the interests of management and workers may conflict.

As professionals, occupational and environmental health nurses have a responsibility to observe professional codes and uphold practice standards. Occupational and environmental health nurses demonstrate fairness in conflict resolution. The promotion of health and safety and prevention of injury and illness at the worksite requires occupational and environmental health nursing representation and participation in the decision-making process within institutional and political arenas. Occupational and environmental health nurses are encouraged to become and remain participants in decision-making processes that define or pertain to occupational and environmental health nursing functions or activities.

Table 26–A. *AAOHN Code of Ethics (continued)*

3. Occupational and environmental health nurses strive to safeguard employees' rights to privacy by protecting confidential information and releasing information only upon written consent of the employee or as required or permitted by law.

Occupational and environmental health nurses have an obligation to maintain the trust bestowed upon them by clients and to protect their clients' rights to privacy. Public trust is ensured by maintaining the confidentiality of health information through prevention of unauthorized access. Written policies and procedures should guide the access, release, transmittal, and storage of health information, including computerized records.

Occupational and environmental health nurses are encouraged to use current professional literature and resources for guidance. Occupational and environmental health nurses are knowledgeable about and adhere to the organizational, local, state, and federal policies and laws governing access to confidential information. Employees are then protected from unauthorized and indiscriminate access and disclosure of health and/or personal information. Confidentiality is crucial to the effectiveness of the occupational and environmental health program.

4. Occupational and environmental health nurses strive to provide quality care and to safeguard clients from unethical and illegal actions.

Occupational and environmental health nurses are dedicated to providing quality, competent, and professional services to their clients. Occupational and environmental health nurses are representatives of the profession and demonstrate competent, ethical, and professional conduct and accountability. The profession's primary commitment is to the health, safety, and welfare of clients. Occupational and environmental health nurses strive to protect their clients and the profession from incompetent professionals and individuals who misrepresent themselves and the profession. Any person or persons who exhibit incompetence or engage in unethical or illegal activities may be reported to licensing, accrediting, or certifying authorities, as may be appropriate. Occupational and environmental health nurses should participate in the development of policies to promote competent, ethical, and legal nursing practice. Occupational and environmental health nurses have a commitment to comply with the laws and regulations that govern the workplace in an effort to provide workers with a safe and healthful workplace.

5. Occupational and environmental health nurses, licensed to provide health care services, accept obligations to society as professional and responsible members of the community.

As licensed health professionals, occupational and environmental health nurses have an obligation to their clients, employers, communities, society, and profession to demonstrate credibility and competence. Occupational and environmental health nurses are responsible citizens in the community adhering to all laws and statutes (local, state, and federal), including those governing occupational and environmental health practice. As professionals, occupational and environmental health nurses respect their clients' and society's rights to know and to receive factual information about potential and actual job and environmental hazards. Occupational and environmental health nurses are knowledgeable of community issues and dilemmas affecting health, safety, and the welfare of society and participate in appropriate resolution when able.

Table 26–A. *AAOHN Code of Ethics (concluded)*

6. Occupational and environmental health nurses maintain individual competence in health nursing practice, based on scientific knowledge, and recognize and accept responsibility for individual judgements and actions, while complying with appropriate laws and regulations (local, state, and federal) that impact the delivery of occupational and environmental health services.

Occupational and environmental health nursing is dedicated to promoting competent professional practice. Occupational and environmental health nurses have the responsibility to strive for excellence and maintain a level of knowledge, judgement, technical skills, and professional values necessary for delivering health services. Individual professional licensure provides for protection of the public to ensure that basic professional competencies have been achieved. Occupational and environmental health nurses utilize professional and educational activities to improve professional practice.

Occupational and environmental health nurses may engage in professional, educational, and quality improvement activities, such as peer review. Occupational and environmental health nurses acknowledge the importance of continued and advanced educational activities beyond the basic level of nursing education. As professionals, occupational and environmental health nurses have a personal and professional responsibility to maintain competence in practice. All occupational and environmental health nurses are professionally and morally accountable for their actions and compliance with nurse practice acts, standards of practice, and other laws/regulations governing occupational health practice. In a situation where occupational and environmental health nurses do not have the necessary skills or knowledge or are unable to render services personally, the nurses have a moral responsibility to refer the client to appropriate services.

7. Occupational and environmental health nurses participate, as appropriate, in activities such as research that contribute to the ongoing development of the profession's body of knowledge while protecting the rights of subjects.

Research is an integral part of occupational and environmental health nursing practice. Research provides new information to improve and validate the tenets underlying the profession's scope of practice. This validation can be accomplished by designing studies, testing theories to guide nursing practice, utilizing and applying research findings, or participating in the research process. Occupational and environmental health nursing, as an applied discipline, engages in scholarly inquiry to build upon the body of knowledge that serves as the foundation for practice. Occupational and environmental health nurses must strive to create and expand this body of knowledge, both empirically and theoretically, through research activities.

Research activities are usually approved by appropriate bodies, such as institutional review boards. Occupational and environmental health nurse researchers should respect and protect the autonomy, rights, and privacy of the subjects. One mechanism to ensure this respect and protect subjects is by voluntary informed consent. Occupational and environmental health nurses have moral obligations to self, their clients, the profession, and society to conduct sound ethical research. Occupational and environmental health nurses have the responsibility to communicate and disseminate research findings to other occupational and environmental health nurses and professionals and to appropriately utilize research findings within their practice.

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completion of an examination. For those occupational health nurses already certified in occupational health nursing (as either COHN or COHN-S), a case management certification (COHN/CM or COHN-S/CM) is now available for those with evidence of case management continuing education, and successful completion of an examination.

Additional academic preparation as a manager, nurse practitioner, or clinical nurse specialist in occupational health nursing is available at the graduate level at University-based, NIOSH-funded, educational research centers. Certification in these advanced practice roles is currently available through the American Nurses Credentialing Center.

THE PRACTICE OF OCCUPATIONAL HEALTH NURSING

Models of Occupational Health Services

There are several models for occupational health service delivery, ranging from on-site salaried personnel to off-site contractual arrangements (Burgel, 1993). The scope of occupational health services depends on the following key industry variables:

- ➢ Company size and demographics of the workforce
- ➢ Geographic distance to a health care facility in the community
- ➢ Type of industry (manufacturing versus service)
- ➢ Hazard profile (review of OSHA 200 log, emergency response needs, potential exposures/trends in claims)
- ➢ Risk management and health benefit philosophy of company; percent of insured workforce
- ➢ Economic resources
- ➢ Self-insurance status for workers' compensation and personal health care
- ➢ Organizational climate, specifically regarding health, hazard communication, and the value of prevention activities

Other team members, depending on an assessment of the above industry variables, may include an industrial hygienist, occupational medicine physician, safety professional, ergonomist, physical therapist, employee assistance program personnel, and rehabilitation counselor.

Depending on the education, expertise, and skills of the nurse, the OHN may take a more involved role in direct care (for example, the nurse practitioner role), case management, employee assistance program activities, ergonomics, safety activities, and environmental monitoring.

Occupational health service models vary not only in the type and extent of health service personnel, but also the degree to which they manage work-related and nonwork-related health care conditions. Some programs manage only work-related injury and illness, with referral of those health problems not directly related to work. Others manage all work-related and a limited number of nonwork-related health concerns. A growing number are offering full-service, 24-hour managed care to employees and their dependents, for both work- and nonwork-related conditions, using advanced practice occupational health nurses (Burgel, 1993; Dowrick & Rezents, 1993; Burgel, 1996; AAOHN, 1999).

Critical to program design is to maintain a focus on a safe and healthy workplace, in recognition that most work-related injury and illness is preventable. Additionally, the safety and environmental monitoring functions and health functions in an organization need to be administratively linked for a successful and smoothly running program.

OHN Staffing and Outcomes

New health and safety regulations, mental health issues in the workplace, the continued increase in cumulative trauma disorders, chronic illness and the aging workforce, the increased numbers of women in the worksite, and the changing health care delivery structures are but a few of the current health issues facing employers. Occupational health nurses are cost-effective providers who manage these complex health issues for employers and employees, while valuing a prevention agenda. Knowledge of the key players—the employee, the supervisor, coworkers, the union representative, family members—in addition to knowledge of the work process, allows for worksite interventions to prevent, for example, a work-related stress claim.

Moderate-to-large employers predominantly employ OHNs with more than 500 employees, and, for those smaller employers the OHN may be the only health care provider on-site. Current recommendations for manufacturing industries is to have one full-time OHN for every 300 employees; and for service industries to have one full-time OHN for every 750 employees (AAOHN, 1994). In more than 60 percent of companies, the occupational health nurse is the sole health care provider at the worksite. In early research done in 1978, recognizing that the OHN was the predominant provider of health care in small industry, NIOSH conducted a study on the costs and benefits of occupational health nursing. Four pairs of manufacturing facilities with fewer than 1000 employees were studied, with documented direct and indirect benefits for both employers and employees. NIOSH concluded that the occupational health nurse was cost-effective, especially in those industries with hazardous work processes and in those companies who had not already established cost-effective alternatives to the delivery of occupational medical care (NIOSH, 1980).

Additional surveys conducted by NIOSH, the National Occupational Hazard Survey in 1972 and the National Occupational Exposure Survey in 1981–83, described the health and safety conditions of the American workforce, and documented trends of worker access to on-site health services. In 1981–83, 3.8 percent of employers with fewer than 100 employees reported the presence of a health unit at the worksite, 32 percent of employers with 100–499 employees reported an on-site health unit, and 87 percent of industries with 500 or more employees reported an on-site health unit (US DHHS, 1988). Over this 10-year

Table 26–B. *Guidelines for Confidentiality of Health Information*

I. Basic Premise

Confidentiality of health information is a concept that is fundamental to good occupational and environmental health nursing practice. Communication between employee and provider is optimal when the client is assured that personal information shared with the occupational and environmental health nurse will be placed and remain in the health record. Also important is assurance that access to health information will be to health providers within the company with disclosures only for the following exceptions:

A. Life threatening emergencies.
B. Authorized release to others, e.g., employee, insurance company, personal health care provider.
C. Workers' compensation information.
D. Compliance with government regulations.

II. Levels of Confidentiality

Three levels of confidentiality are identified that require increasing control of access. Level III information is the most controlled.
Level I—Information required by law. These include data on occupational and environmental illnesses and injuries, exposure data and information derived from special examinations, such as food handlers.
Level II—Information to assist Human Resource Management. This includes information obtained from job placement and provider health surveillance and other exams to determine workability status of the employee.
Level III—Personal Health Information. This includes all information not recorded in Level I or II. Examples are treatment for non-work related health problems or family health counseling.

A. **Control and Access of Level I and II Information.**
   1. All disclosures should be coordinated and controlled by the occupational and environmental health nurse.
   2. Disclosure is made to the employee or the employee's designated representative with appropriate written consent.
   3. Management disclosure is made on a need-to-know basis with reference only to workability status.

B. **Control and Access of Level III Information.**
   1. All information is controlled by the occupational and environmental health nurse.
   2. Employee disclosure is made only upon appropriate written authorization.
   3. No disclosure is made to management.
   4. No disclosure is made to regulatory agencies.
   5. Disclosure to health insurance providers is made upon appropriate written authorization.

III. Circumstances of Disclosure

Include these elements in written policies directing record disclosure:

A. Authorization for disclosure shall be in writing and state specifically what information is to be disclosed.
B. Describe how (in what manner) information is to be disclosed.
C. Provide a time frame for disclosure. A 15 day access period is required in the OSHA standard.
D. Interpretation of health information by health professionals shall be available.
E. Personal information to outside sources (OSHA, epidemiologic/research activities) is provided as aggregate, anonymous data.

IV. Database Security

Procedures to insure security of records must be established and maintained.

A. Establish security systems for both manual and computerized record systems.
B. Provide for back up systems in the event of electrical failure, fire or flood which can destroy records.
C. Transfer records in a manner which safeguards privacy.
D. Provide confidentiality training for staff (handbooks/manuals).
E. Develop a disciplinary Procedure for violation of security.
F. Identify (i.e., badges) individuals requesting health record information.

V. Storage

Concern for confidentiality is addressed in developing record format, filing and storage systems.

A. Establish a format which provides for separation of records—Level I and II information from Level III.
B. Determine specific placement for file(s) which insures greatest privacy.
C. Limit access to records.
D. Provide for locked security.

American Association of Occupational Health Nurses. Atlanta: AAOHN, 1998.

period there was an increase in access to nursing services on-site, a slight decrease in on-site physician services, with an associated increase of contractual agreements with off-site physicians (Pederson and Sieber, 1989). More recent data is not available; however, 49 percent of AAOHN members report being the only registered nurse at their location; and 54.5 percent report working with employers with fewer than 1000 employees at their location (AAOHN, 1995, pp. 23, 24).

Large employers are very aware of what they need from on-site occupational health nurses. Lusk, Disch, and Barkauskas (1988) found in their survey of Fortune 500 companies (N=173) that 90 percent employed registered nurses, 61 percent employed safety engineers, 61 percent employed physicians, and 45 percent employed industrial hygienists, documenting the predominance of nursing expertise in large industries. This survey notes the four most frequent occupational health nursing activities as:

- ➢ Supervising the provision of nursing care for job-related emergency and minor illness episodes (90%)
- ➢ Counseling employees regarding health risks (88%)
- ➢ Providing case management for employees with workers' compensation claims (67%)
- ➢ Performing periodic health assessments (63%)

Lusk et. al. (1988) also evaluated desires of employers relative to future role functions of the OHN. The four most frequently reported desired activities were for the OHN to:

- ➢ Generate analyses on trends in health promotion, risk reduction, and health care expenditures (36%)
- ➢ Develop special health programs particular to the needs of the corporation (29%)
- ➢ Make recommendations for more efficient and cost effective operation of the health care department (29%)
- ➢ Conduct research to determine cost-effective alternatives to health care programs and services (29%)

A similar survey of Ohio employers found similar results, underscoring the need for OHNs to have fiscal and evaluation skills (Martin et al, 1993).

In another study of a Fortune 500 company and its national sites (Bey et al, 1988), an analysis of the OHN role was studied from both the OHN (N= 26) and the manager (N=15) perspective. Both nurses and managers ranked direct care of employees as the highest priority, followed by health education and counseling (#2 for occupational health nurses, #3 ranking for managers), medical management (#3 for occupational health nurses, #2 for managers), record-keeping (#4), health promotion (#5), and environmental hazard recognition and control (#6). Of these functions, managers ranked direct injury/illness care, health education and counseling, and medical management as nursing benefits to the company.

Many studies have documented the quality outcomes and associated cost savings of using advanced practice nursing in the clinical management of work- and nonwork-related injury and illness (Touger & Butts, 1989; Dalton & Harris, 1991; Burgel, 1993). Hospital-based occupational health services delivered to local industries were found to be cost effective using a nurse practitioner model of service delivery (Konstantinos and Crespo, 1998). These services primarily involved work-related injury treatment and case management, with direct reimbursement by the workers' compensation carriers to the clinic. Additional indirect profit areas for the hospital included the pharmacy, radiology, laboratory, and specialty referrals generated by the injury treatment center. One study of a medical surveillance program, managed by an OHN, documented continued customer satisfaction, quality outcomes, and overall cost savings of several medical monitoring programs (hearing conservation, asbestos screening, Department of Transportation exams) when compared to using an external vendor. Program highlights included use of a nurse practitioner/physician assistant to conduct the examinations, and an enhanced health promotion service, including the provision of immunizations (Lukes, 1998).

Table 26–C. ***AAOHN Research Priorities***

1.	Effectiveness of primary health care delivery at the worksite.
2.	Effectiveness of health promotion nursing intervention strategies.
3.	Methods for handling complex ethical issues related to occupational health.
4.	Strategies that minimize work-related health outcomes (e.g., respiratory disease).
5.	Health effects resulting from chemical exposures in the workplace.
6.	Occupational hazards of healthcare workers (e.g., latex allergy, bloodborne pathogens).
7.	Factors that influence workers' rehabilitation and return to work.
8.	Effectiveness of ergonomic strategies to reduce worker injury and illness.
9.	Effectiveness of case management approaches in occupational illness/injury.
10.	Evaluation of critical pathways to effectively improve worker health and safety and to enhance maximum recovery and safe return to work
11.	Effects of shift work on worker health and safety.
12.	Strategies for increasing compliance with or motivating workers to use personal protective equipment.

Rogers B, Agnew J, Pompeii L. Occupational health nursing research priorities: A changing focus. *AAOHN Journal* 48(1):9–16, 2000.

OHN Role and Levels of Prevention

The OHN role requires knowledge, skills, and abilities in the following competencies:

- ➢ Clinical and primary care
- ➢ Case management
- ➢ Work force, workplace, and environmental issues
- ➢ Regulatory/legislative issues
- ➢ Management
- ➢ Health promotion and disease prevention
- ➢ Occupational and environmental health and safety education/training
- ➢ Research
- ➢ Professionalism (White et al, 1999)

The OHN uses all of the above competencies, often in a blended role, to accomplish a wide range of programmatic activities in the worksite (Figure 26–3). For example, establishment of an ergonomics program requires knowledge, skills, and abilities in:

a. The diagnosis and treatment options for repetitive strain injuries (clinical and primary care)
b. Program design with policy and procedures (management)
c. The ability to educate workers regarding neutral wrist position and postural issues (education/training; health promotion and disease prevention)
d. Knowledge of ergonomics legislation and the Americans with Disabilities Act (regulatory/legislative)
e. A team approach to analyze the workstations and institute engineering controls (workforce, workplace, environmental/research, and professionalism)

Figure 26–3. The OHN uses competencies, including clinical and primary care; case management; worforce, workplace, and environmental issues; regulatory/legislative; management; health promotion and disease management; occupational and environmental health and safety education/training; research, and professionalism—often in a blended role, to accomplish a wide range of programmatic activities in the worksite.

OHN role functions include involvement at each level of prevention: primary, secondary, and tertiary. *Primary prevention* refers to those health promotion and health protection measures that prevent the occurrence of disease and injury. Immunizations are a primary preventive measure, as are engineering controls. *Secondary prevention* is the early detection and treatment of disease and injury so that progression is slowed or complications are limited. Screening is a secondary prevention measure to detect asymptomatic disease early in the disease progression; for example, blood lead testing is a secondary preventive measure to detect lead exposure before symptoms of lead toxicity are present. *Tertiary prevention* is the prevention of disability through rehabilitative efforts. Modified duty or transitional work programs are a tertiary disability management strategy, aimed at increasing function and preventing prolonged disability.

The following programmatic components, arranged around levels of prevention, are discussed in more detail:

Primary Prevention
- ➢ Preplacement (postoffer) evaluations
- ➢ Immunizations
- ➢ Employee training
- ➢ Wellness programs
- ➢ Employee assistance programs

Secondary Prevention
- ➢ Assessment and management of health complaints
- ➢ Health/medical surveillance

Tertiary Prevention
- ➢ Case management
- ➢ Modified duty programs

Programs Commonly Managed by OHNs
- ➢ Workers' Compensation
- ➢ Americans with Disabilities Act
- ➢ Recordkeeping
- ➢ Bloodborne Pathogens
- ➢ Ergonomics
- ➢ Evaluating Outcomes of OHN Activities

Primary Prevention

PREPLACEMENT (POSTOFFER) EVALUATIONS

Preplacement evaluations are a primary prevention activity, with the goal to place workers in jobs based on physical capabilities and making reasonable accommodations, if needed and in compliance with the Americans with Disabilities Act (ADA). Critical to ADA compliance is the need to insure that all evaluations are job-related, and offered to all entering employees within the same job class (Pruitt, 1995). Key to the success of a preplacement program is the valuable process of creating a job analysis for each job class. Although time-consuming, this activity involves active dialogue with the supervisor, human resources, representative employees, and the OHN to identify both the physical and emotional requirements of a position. This can provide a powerful opportunity to vary job tasks, remove unrealistic lifting expectations, and push for engineering controls, while discussing possible accommodations that promote healthier job tasks for all.

Another value of the preplacement evaluation is that the OHN can introduce the role of the occupational health service and establish a beginning relationship with the new employee. At this time, an expectation can be set for active participation of the employee in recognizing and reporting potentially hazardous working conditions.

The value of preplacement evaluations is most visible in those positions that are safety-sensitive, for example, determining fitness for duty in the transportation industry. However, in one study looking at musculoskeletal injury outcome after preplacement assessment, no injury rate difference was found between the preplacement group and a matched case

group of employees who had not participated in the preplacement program (Nachreiner et al, 1999). One may anticipate a reduction in injury rates for those employees appropriately placed in jobs matched to their physical and mental abilities. An alternative interpretation is to note that there was not an increased injury rate in this study for those workers who were working with work restrictions prescribed during the preplacement process. Additional value in the preplacement process can be illustrated in the current debate around latex sensitivity. Use of a preplacement process for latex sensitivity in hospital environments will drive the dialogue about how best to identify atopic individuals at higher risk for developing latex sensitivity, and how best to accommodate these employees. Simultaneously, there will be policy discussions about "latex-safe" versus "latex-free" environments, and a planned educational intervention to increase overall awareness. The prevention of just one case of latex sensitivity can often justify the cost of these preventive activities.

IMMUNIZATIONS

Approximately 45,000 adults in the United States die annually of complications from influenza, pneumococcal infections, and hepatitis B—the primary vaccine-preventable diseases affecting adults (Centers for Disease Control and Prevention [CDCP], 2000). The total economic cost of treating these vaccine-preventable diseases among adults, excluding the value of years of life lost, exceeds $10 billion each year (CDCP, 2000). The worksite is considered an ideal site for immunization delivery. OHNs are often engaged in designing worksite immunization programs, which may be mandatory (for example, bloodborne pathogens and hepatitis B vaccination for at-risk employees), or voluntary. One worksite influenza vaccine program at a Department of Energy nuclear facility demonstrated reduced influenza-like illness, related lost work time, and reduced health care utilization in 789 vaccinated employees (Dille, 1999).

EMPLOYEE TRAINING

More than 100 OSHA standards require the employer to train employees in health and safety (U.S. DHHS, 1998). Many of the occupational and environmental health and safety objectives in *Healthy People 2010* require training as well (US DHHS, 2000). Employee training, either in 1:1 or group settings, encourages workers to engage in safe work practices and stimulates a level of understanding to recognize and report potential hazards to employers.

A key OHN activity in all employee training is the needs assessment phase. One component of a needs assessment is to determine if there is a knowledge, behavior, or skill deficit that would appropriately respond to a training intervention. The needs assessment also includes a walkthrough survey to identify real and potential hazards, and the efficacy of current engineering, administrative, and personal protective controls. Review of the literature will outline possible solutions for the training need, including learning methods that are culturally sensitive and literacy-level–appropriate. Ways to evaluate outcomes to determine if the training was successful is included in the training plan. Risk communication principles outline ways in which to make the hazard more real and imaginable to the employee, with a clear understanding of how the hazard can be controlled by taking action. Involvement of a task force in the planning of the training will build in success. Pilot testing a risk communication strategy with the task force is recommended prior to full implementation of the training (U.S. DHHS, 1998).

OHNs are often involved in the employee training requirement in the Hazard Communication standard. Using a team approach and often involving joint labor-management representatives, the OHN educates employees on potential health effects from potential exposures with hazardous substances, including interpretation of the material safety data sheets (Brooks et al, 1994; Robins et al, 1994).

Examples of other OHN employee training activities include:

- ➢ Education on how best to adjust workstations and work flow to decrease the number of forceful repetitions and thus prevent cumulative trauma disorders
- ➢ Education on the long-term effects of noise on hearing and the need for hearing protection
- ➢ Education and demonstration on dividing the lifting loads, in addition to teaching back strengthening and proper lifting techniques

WELLNESS PROGRAMS

OHNs have long been involved in wellness initiatives in the worksite. In *Healthy People 2010*, the two broad goals for our nation are to increase the quality and years of healthy life, and to eliminate health disparities amongst ethnic, racial, and socioeconomic groups in America. One specific objective is to increase the proportion of worksites that offer a comprehensive employee health promotion program to their employees, with the goal of 100 percent of worksites with more than 50 employees by the year 2010 (U.S. DHHS, 2000).

In 1999, 95 percent of worksites with more than 50 employees reported offering at least one health promotion activity (U.S. DHHS, 2000). This growth since 1985 is striking. However, many of the programs lack sufficient design, and participation rates are generally low. The challenge remains to engage those workers in the crafts, trades, services, and administrative support so that these employees participate in worksite health promotion efforts (U.S. DHHS, 2000; Lusk, 1997).

In one comprehensive review of worksite health promotion literature, most of the studies demonstrated a health benefit or a cost savings, evaluating clinical outcomes such as improved blood pressure control, and/or an administrative outcome, such as health care utilization or a reduction in absenteeism (Lusk, 1997). A comprehensive approach to wellness program design is imperative, using the demographics of the worksite

population to prioritize program priorities. Examples of wellness programs aimed at primary prevention include exercise for health, prenatal education, and nutrition guidelines. Risk reduction programs are also beneficial at the worksite, for example, for back injury prevention, smoking cessation, and programs aimed at chronic illness management. In one study of worksite diabetes education in a bank, employees with diabetes demonstrated an improvement in their self-perceived control of their chronic illness, with significant improvements in mean glycohemoglobin levels (Burton & Connerty, 1998).

EMPLOYEE ASSISTANCE PROGRAMS

Employee Assistance Programs (EAPs) use both primary and secondary prevention methods to recognize, assess, treat, and refer those personal and mental health problems that impact job performance. Approximately 33 percent of all private, nonagricultural worksites with more than 50 employees reported an EAP resource for their employees (Hartwell et al, 1996). Although initially focused on substance abuse, EAPs are now assessing a full range of family and work issues that may affect an employee's ability to be a fully functioning member of a work team. These services may be crisis oriented and in response to changes in work performance, but also be preventive in nature, with an emphasis on communication, conflict resolution, and stress management. The OHN is often the first point of contact, and is able to confidentially counsel and refer employees to an EAP resource.

Emphasis on the appropriate use of psychiatric, chemical dependency, and other services by employees and their dependents is a current case management program in many industries. Growing mental health care costs continue to be a large concern for corporations. The OHN manages, implements, and cooperates with the EAP resource at the worksite, and is the gatekeeper to mental health care providers in the community. This strong link impacts mental health care in two ways: the employee is educated by the OHN in purchasing mental health care for themselves or their dependents; and the OHN becomes involved in supporting this individual at the worksite.

Stress at the workplace and at home, workplace violence, drug and alcohol use/abuse, and accommodating employees with psychiatric diagnoses are just a few of the daily challenges facing OHNs. OHNs are often the first resource for the troubled employee, and a common role function is to complete the initial assessment and facilitate referral for long-term treatment.

Secondary Prevention

ASSESSMENT AND MANAGEMENT OF HEALTH COMPLAINTS

Most commonly, an employee has an interaction with the OHN for a health complaint. This may be an acute problem, such as wrist pain or an earache, or a visit for a chronic health problem, for example, a blood pressure check or a question regarding a medication dose. At all times, the OHN must evaluate this symptom in relationship to the work tasks done by the employee (Twining, 1995):

- ➢ Is there a potential exposure that could cause or aggravate the complaint?
- ➢ Was there a change in the work process that could account for this symptom?
- ➢ Are other coworkers complaining of similar symptoms?
- ➢ Is the employee still capable of performing their work, without threat to self or others? If no, what accommodations are needed?

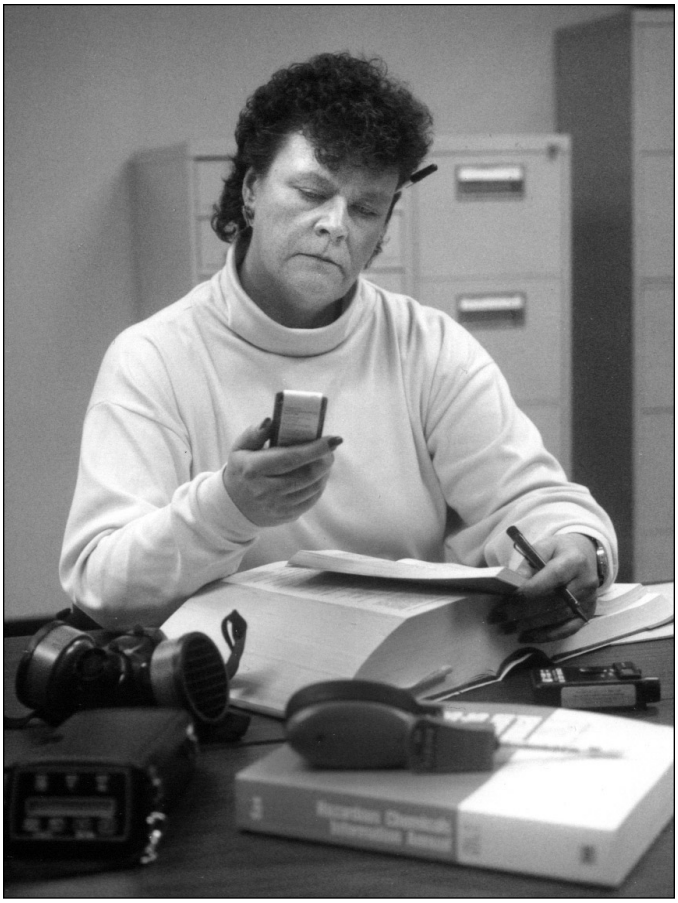

Figure 26–4. The OHN needs access to the most recent environmental monitoring data, to fully evaluate the potential work relationships. (© Photo by Avery Photography per ABOHN, Inc.)

The OHN needs access to the most recent environmental monitoring data, so as to fully evaluate the potential work relationships (Figure 26–4).

The OHN also knows the individual's prior health history, the family system, and the current department work group issues, and therefore can identify if psychosocial issues (both at home and at work) may be influencing this complaint.

The OHN, depending on resources, skills, and expertise, may do the initial evaluation and treat within a first aid/self-care model and refer, if needed, for a more comprehensive medical evaluation. Or, the OHN may do the initial evaluation and treat according to standardized procedures, without a physician referral, and dependent on state regulation of nursing practice.

If the condition is work-related, the OHN is in a crucial position to conduct a walkthrough survey to identify the root cause of the injury and institute preventive measures. The OHN will educate and advocate about the worker's compensation benefit, and monitor recovery and return to work in a case management role.

The OHN uses practice guidelines to evaluate the clinical outcomes of medical care, and, if doing case management for a worker compensation carrier, the OHN may use practice guidelines to authorize specific diagnostic or treatment interventions. Practice guidelines are clinical practice recommendations based on a critical review of research/evidence. There are numerous practice guidelines, some focused on the diagnosis of a specific health condition, and others focused on the clinical management of a health condition, with the key aim to standardize care. The American College of Occupational and Environmental Medicine published a set of guidelines specific to work-related musculoskeletal complaints (Harris, 1997). Other purposes of clinical practice guidelines include the goal to reduce variation in practice across geographic regions and across providers, to improve the quality of health care, and to promote best practices and cost consciousness. Many occupational health settings use practice guidelines as a quality assurance/audit tool to evaluate clinical outcomes of care, and to assist in the disability management process.

SCREENING

Screening tests aim for early detection of asymptomatic disease with the goal that treatment can render an improved outcome. "Put Prevention into Practice" is a program of the Office of Disease Prevention and Health Promotion; it includes health education materials, *The Clinician's Handbook of Preventive Services*, and other resources that are valuable in worksite screening programs (US DHHS, 1998). *The Guide to Clinical Preventive Services* (2nd ed.) provides research-based screening recommendations for the clinician, many of which can be reinforced in a wellness initiative at work (U.S. Preventive Services Task Force, 1996). These screening tests can be offered in coordination with the personal health plan, to avoid duplication of services. Examples of common screening programs in the worksite are cholesterol testing and prostate cancer screening.

HEALTH/MEDICAL SURVEILLANCE

Occupational health surveillance is the process of monitoring the health status of worker populations to gather data about the effects of workplace exposures and to use the data to prevent illness or injury (AAOHN, 1996).

The goal of health/medical surveillance is early identification of biological markers or endpoints that may signify exposure. Health/medical surveillance, often a requirement of federal health and safety standards, is designed, coordinated, implemented, and evaluated by the OHN, such as conducting a hearing conservation program, respiratory protection program, or asbestos surveillance (Papp & Miller, 2000; Rogers & Livsey, 2000).

The OHN reviews the environmental monitoring data, reviews the toxicology of the substance, and in consultation with industrial hygiene and/or occupational medicine, outlines a health surveillance program that is exposure and job specific. Common to OHN practice is the communication and counseling of test results to the individual employee and to the primary care provider. The OHN develops policies and procedures in anticipation of the potential need for job rotation, job modification, confidentiality, and other potential ethical dilemmas that may arise when an abnormal finding is discovered during health/medical surveillance activities. Good communication skills, used to educate and counsel employees regarding the purpose and use of these test results, are of paramount importance.

Tertiary Prevention

CASE MANAGEMENT

Case management is the timely coordination of quality health services with the goal to decrease fragmentation of care, enhance the client's quality of life, and to contain health care costs (Salazar et al, 1999). It is a system which aims to provide the right care, at the right time in the right setting by the right provider and at the right cost. The emphasis is on early intervention and coordination of care for those targeted high-risk, high-cost cases.

Frequent and timely communication is an important component of case management. For example, an employee or dependent sustains a spinal cord injury and the OHN recommends early transfer to a spinal cord rehabilitation facility. However, this facility is 100 miles from the family's hometown. Clear OHN communication with the family is needed to explain the anticipated improved outcome in the rehabilitation facility and to gain their support of the transfer.

There are several tools that OHNs use to establish a case management program (Salazar & Graham, 1999):

- ➢ The ability to flag catastrophic and chronic claims, for example: premature births, spinal cord injuries, organ transplants, certain cancers, AIDS, mental health disorders.
- ➢ Early identification of workers' compensation cases with high reserves and those injured workers at risk for delayed recovery.
- ➢ Establishment of a pool of modified duty jobs.
- ➢ Establishment of a panel of qualified providers who support an aggressive, medical rehabilitation plan with modified duty.
- ➢ Access to computerized information systems.
- ➢ Full knowledge of health benefit packages in the event that alternate benefits need to be negotiated on behalf of the ill employee or dependent, for example, home care with nursing assistance.

TRANSITIONAL/MODIFIED DUTY PROGRAMS

Timely return to work, in temporary transitional or modified duty assignments, is a realistic outcome measure for a case management program targeting both nonwork and work-related injuries and illnesses (Brines et al, 1999). Advocating for safe transitional work is a major role for the OHN. The OHN not only knows the work process, but also has been very involved in determining the level of care needed for an injured employee. Therefore, the OHN is well positioned to determine readiness to return to work, and to support both the injured employee and his/her supervisor throughout the process. An aggressive sports medicine rehabilitative approach, in addition to modified duty, helps prevent delayed recovery of injured workers (Gliniecki & Burgel, 1995).

Establishment of a transitional work program requires a proactive approach with policies and procedures that support placement based on objective functional capacity into positions that are meaningful and productive (Evangelista-Uhl & Loomis, 1999). In an extensive review of the literature on return to work programs, Krause et al found that those injured workers who were offered modified work returned to work twice as often to those not offered (Krause et al, 1998).

A clear written contract is established between the injured worker and the OHN which outlines work and schedule expectations, the communication link between the department and the OHN, how work performance will be evaluated, and payroll issues (Horstman et al, 2000). This is a time-limited contract, with the expectation that as the employee progressively improves, the physical demands of the job will advance as well. Therefore, transitional work is, in reality, on-the-job work hardening. It is also imperative to have a panel of health care providers who philosophically support transitional work as a therapeutic intervention (Gliniecki & Burgel, 1995).

Programs Commonly Managed by OHNs

WORKERS' COMPENSATION

Job-related injuries cost employers billions of dollars per year in direct workers' compensation expenses, which include costs for medical care, temporary and permanent disability, vocational rehabilitation, and medical-legal costs. Additionally, there are indirect costs associated with re-training replacement workers, lost productivity, workplace accommodation, and other preventive efforts. Injured workers also sustain severe economic consequences from workplace injuries, specifically in lost earnings. OHNs are often very involved in the management of the workers' compensation program for employers, or may be in a case management role with the workers' compensation insurance carrier.

Workers' compensation is a very complex system in many states. Injured workers often do not know how to access these benefits, and can become quickly confused and angry if they are attempting to negotiate this system alone. The OHN, on-site, is often the first contact for an injured worker, able to explain the full scope of workers' compensation benefits. A case management approach is used by the OHN to determine the appropriate care needed and whether work modifications are required. Close communication with and monitoring of workers' compensation cases is an important OHN role.

AMERICANS WITH DISABILITIES ACT

Some 43 million Americans have one or more physical or mental disability. This population is targeted by the Americans with Disabilities Act (ADA) (Public Law No. 101336). The ADA, signed into law in 1991, prohibits discrimination against people with disabilities in employment, transportation, public accommodation, activities of state and local government, and telecommunication relay services.

Employers must not only have nondiscriminatory selection criteria, but must make reasonable accommodation to the known limitations of the qualified applicant unless it causes undue hardship. OHNs advise employers on compliance with the requirements of the ADA, insuring that the preplacement (postoffer) program meets the ADA requirements. In addition, OHNs often recommend reasonable accommodations and counsel employees with physical disabilities. The OHN provides the link between the ADA and other legislative/regulatory benefits, such as the Family Medical Leave Act, and the workers' compensation benefit, seeking legal consultation if needed (Guzik, 1999). (See Table 26–D.)

RECORDKEEPING

Maintenance of OSHA 200 logs is often an OHN responsibility. As required by OSHA standard, the OHN determines level of care and treatment, and if it requires only first aid, it is not OSHA recordable. Recordable conditions include: every death, every occupational illness and injury which involves medical treatment beyond first aid, lost time, work modification, job transfer, or any loss of consciousness. The OSHA 200 log is posted every year from February 1–March 1. (Please note: The proposed new recordkeeping standard is still in the paperwork reduction act.) Reporting requirements for workers' compensation vary from state to state, and these requirements are separate from OSHA recordkeeping requirements. The employers' report of occupational injury and illness can be substituted, in many cases, for the supplemental OSHA Form 101.

The OSHA 200 log is one data source for OHN analysis for trends of work-related disease. This data helps prioritize walkthrough surveys, periodic environmental sampling, health/medical surveillance programs, and employee training schedules.

Access to employee exposure and medical records, as required by OSHA standard, is an additional OHN responsibility. Establishment of a confidential recordkeeping system is a priority from a legal and ethical perspective. (See Tables 26–A, 26–B.) Employees and their designated representatives have access to aggregate exposure records of other

Table 26–D. ***Americans with Disabilities Act: Reasonable Accommodations***

Job	*Essential Function*	*Disability*	*Possible Accommodations*
Material handler	Routinely move pkgs. weighing 40–50 lb (18.14–22.68 kg)	No lifting over 25 lb (11.34 kg)	1. Mechanical assist (roller racks, hoists) 2. Dual-person lifts
Computer operator	Rotation of shifts	Fatigue: postchemotherapy	1. Split-shift 2. Part-time job 3. Job-share
Mail carrier	Work outside 5 days/week	History of malignant melanoma	1. Provide protective clothing (SPF shirts, hats, gloves)
Engineer	Communicate ideas to work-group	Speech impairment	1. Voice-activated keyboard 2. Portable computer
Housekeeping	Follow instructions	Illiteracy due to retardation	1. All directions in drawing form 2. Cassette tape of instructions with cassette player

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employees with past or present job duties which are similar to the employee's. Exposure records include environmental monitoring data and biological monitoring data. Access need not be provided to voluntary employee assistance records, which are maintained separately from the occupational health medical record.

BLOODBORNE PATHOGENS PROGRAM

The OSHA Bloodborne Pathogens Standard, adopted in 1992, requires employers to establish an exposure control plan for all employees who have occupational exposure to blood or other potentially infectious materials. It mandates the use of universal precautions and the provision of personal protective equipment by the employer, in addition to safe needle disposal containers. Several states have passed stricter requirements for the provision of safe needle devices. The standard clarifies the employer's responsibility to provide, at no cost to at-risk employees, the hepatitis B vaccine series. There are specific training requirements, often a role for the OHN. Postexposure policies and procedures are established by the OHN, as outlined in the OSHA Bloodborne Pathogens Standard and updated by the Centers for Disease Control and Prevention.

The management of this bloodborne pathogen standard involves all OHN role competencies. Because of the confidential nature of an exposure, especially in the uncommon event of an HIV antibody conversion, the OHN must use her/his astute communication and counseling skills and strong professional ethics.

ERGONOMICS

OHN involvement with ergonomic programs continues to grow. Often an interdisciplinary activity involving the job design personnel of an industry, the practice of ergonomics involves workstation evaluation, job analysis, and training. Work-related musculoskeletal disorders are common in an office, manufacturing, or hospital setting, and are predominant in those positions with the following risk factors: force, repetition, duration, contact stressors, awkward postures, cold temperature, and vibration (Ostendorf et al, 2000). An ergonomic program consists of management commitment, worksite analysis, hazard prevention and control, medical management, and training and education.

Because of the waxing and waning of symptoms, employees need education and counseling about work-related musculoskeletal disorders, with measures to prevent but also treat the acute flares of this condition. With ergonomic educational programs, there often is an increase in the number of symptomatic employees who present for a health evaluation. However, if engineering controls are introduced and subsequently reinforced on periodic walkthrough surveys by the OHN, the severity of symptoms should decrease over time. Program evaluation for ergonomic interventions, therefore, should detail not only the number of cases, but indices of severity as well.

Evaluating Outcomes of OHN Activities

Evaluating the effectiveness of OHN activities, in the areas of primary health care delivery, case management, ergonomic interventions, and health promotion, is a major theme in the recently revised OHN research priorities (Rogers et al, 2000) (see Table 26–C).

The OHN plays a critical role in the evaluation of the occupational health services, and this often includes collecting health and corporate outcomes data (Kosinski, 1998). This evaluation process not only provides for continuous quality improvement, but this data can be used to target activities, establish short and long term goals, define responsibilities of team members, delineate time frames for action items, expected results, and measurements against goals and benchmarks, and offer rationale and support for additional resources for the occupational health agenda.

Health outcomes are the results or consequences of a process of care. Health outcomes may include satisfaction with care, use of health care resources, and clinical outcomes, such as changes in health status and changes in the

length and quality of life as a result of detecting or treating disease (US DHHS, 2000). Selected health outcome indicators for occupational health clinical care to injured workers may include (Rudolph, 1996; Rudolph, 1998):

- ➢ *Access to care:* Initial treatment for nonemergency work-related conditions will be delivered within 24 hours after the injury is reported
- ➢ *Patient satisfaction:* 85 percent of injured workers identified the occupational health nurse as very to extremely helpful in answering questions about the workers' compensation system on satisfaction survey.
- ➢ *Primary prevention:* High-risk health care workers will have documentation in their preplacement record of hepatitis B vaccination offer/immunity.
- ➢ *Secondary prevention:* Occupational health history is documented in 90 percent of those medical records of employees with occupational injury; or, chart documentation of ergonomic evaluation within one week of diagnosis of a work-related upper extremity complaint.
- ➢ *Tertiary prevention:* Sustained return to work, without reinjury, for 90 days after release to return to work; or, litigated cases decreased to five percent after occupational health nurse case management intervention.

SUMMARY

The Occupational Health Nurse, the predominant health provider on-site in industry, is key to a comprehensive occupational health and safety program. The OHN has critical relationships, not only with the employee, but also with the supervisor, other coworkers, the union, family members and the employee's primary care provider. The OHN has knowledge of the work process and potential hazards, and provides the confidential and neutral analysis of the interaction between the worker's health status and his/her job. By using primary, secondary, and tertiary prevention strategies, the OHN uses a team approach to prevent work-related injury and illness and maintain the health of the workforce. Case management, which includes coordination of care for the best care at the right cost, is a key strategy used by the OHN in monitoring both work- and nonwork-related injury and illness care. Evaluation of the effectiveness of key OHN programmatic activities, including primary health care, case management, ergonomic interventions, and health promotion programs, are four future research priority areas in occupational health nursing.

An on-site OHN, either in a full-time or part-time capacity, is a valuable company asset to maintain an emphasis on a safe workplace, manage the occupational health and safety regulatory requirements and to monitor the health care of employees.

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Chapter 27

The Industrial Hygiene Program

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The primary objective of industrial hygiene (IH) is the prevention of occupational disease and injury. The IH program helps manage these risks by implementing methods for anticipating, recognizing, evaluating, and controlling health hazards. A safe and healthful workplace benefits workers as well as the employer by protecting health and safety while improving employee morale and productivity. This chapter provides information on the fundamental elements for developing a new or updating an existing industrial hygiene program.

An effective program begins with obtaining the right skills for designing and implementing industrial hygiene programs. In most cases the industrial hygienist is a professionally trained specialist with a science background consisting of a blend of experience and education. It is common to find industrial hygienists with postgraduate training in industrial hygiene or a related degree in science or engineering with additional course work in specific areas of practice such as sampling methodology and analysis, industrial ventilation, radiation safety, hearing conservation, indoor air quality, toxicology, and ergonomics. These professionals can be staff or vendors from insurance and consulting companies. Since the field of industrial hygiene constantly evolves, so does the need for continuing education.

COMPONENTS OF AN INDUSTRIAL HYGIENE PROGRAM

The industrial hygiene program has a number of components usually beginning with a policy statement which outlines the organization's commitment to employee health and safety. The written program contains elements for hazard recognition, evaluation and exposure assessment, hazard control, employee training and involvement, program evaluation, and documentation. The format of the program depends on a variety of factors including the size and type of the organization, its management philosophy, the range of occupational hazards at the facility, and the available health and safety resources. For

example, small companies may rely on the services and programs provided through their insurance companies or consulting agencies. Larger corporations and government agencies, on the other hand, may have more comprehensive programs and staff support appropriate for their organization's needs.

BENEFITS OF AN INDUSTRIAL HYGIENE PROGRAM

All organizations benefit from the contributions and productivity of its employees. The industrial hygiene program provides social and economic benefits by sustaining a healthful and fit workforce to help meet company objectives. The following benefits have been cited in well-established programs:

- ➢ They provide a place of employment in which employees are protected from all known occupational health hazards at the workplace.
- ➢ Compensable injuries or illnesses are reduced, thus lowering insurance premiums and associated medical and recordkeeping costs.
- ➢ Productivity is usually increased by improving working conditions. Improved working conditions reduce lost time from accidents and illnesses, reduce absenteeism, and improve morale and labor relations.
- ➢ Operating costs are reduced by anticipating and controlling potential occupational health hazards during the design phase of new projects.
- ➢ The Occupational Safety and Health Administration (OSHA) and other government regulations concerning industrial hygiene are quickly assessed and implemented.

In recent years, the introduction of total quality management followed by the ISO (International Organization for Standardization) 9000 (Quality Management and Quality Assurance Standards) and 14001 (Environmental Management Systems) standards have provided businesses with the advantages of continuous improvements from instituting managment systems for quality and environmental practices. There have also been considerations for an Occupational Health and Safety Management System (OHSMS) by a number of organizations aimed at helping businesses realize the value of continuous improvements in health and safety. Each of these approaches generally begin with a policy statement and a cycle of Plan, Do, Check, and Act, devised by W. Edwards Demming in the 1950s. This cycle, which is known and applied in larger organizations, demonstrates how programs which include industrial hygiene contribute to company objectives by maintaining and improving employee health and safety.

ESTABLISHING AN INDUSTRIAL HYGIENE PROGRAM

Written Program and Policy Statement

A policy publicly states a company's commitment to employee health and safety. The industrial hygiene program should align itself with the policy provided by the chief administrator, or top management, of the organization. It should state the purpose of the program and require active participation by all employees reflecting the following:

- ➢ The importance that management places on the health and safety of its employees.
- ➢ Management's commitment to occupational safety and health, which is demonstrated by its placing health and safety at the same level of authority and accountability as production.
- ➢ The company's pledge to comply with all federal, state, and local occupational safety and health regulations.
- ➢ The necessity for active leadership, direct participation, and the enthusiastic support of the entire organization.

PLANNING ACTIVITIES: GOALS AND OBJECTIVES

Typically, a young or immature program will focus on reactive activities such as incidents or new legal/regulatory requirements. As a program matures, more time will be spent in the planning phase of the Demming cycle (Plan, Do, Check, Act), determining ways for continual improvements, voluntary commitments, and preventive actions. The establishment of a strategic plan for long- and short-range goals and objectives is vital to the development of an effective industrial hygiene program. These goals and objectives should also be part of the written program. They are often established by a committee, such as a joint labor–management health and safety committee.

A goal is a desired outcome, whereas an objective is a specific activity or means of achieving a goal. Goals should be realistic and, when possible, measurable. For example, if ergonomics-related injuries are a problem, the goal may be to reduce the number of accidents by 25 percent within a three-year period. The objectives/activities to achieve this goal could include establishing an ergonomics committee, providing ergonomic training for the committee and affected personnel, and selecting an ergonomics consulting firm to provide initial workplace surveys. Goals and objectives should not be static—they should be evaluated and updated on a regularly scheduled basis (Table 27–A). The evaluation process may determine that the objectives are inadequate or that the goals are not well enough defined. In addition, as conditions change, there may be new problems to address, in which case new goals and objectives should be developed. The written program thus becomes a continually updated document.

PROCEDURES AND REQUIREMENTS FOR COMPONENTS OF THE IH PROGRAM

The written industrial hygiene program can be subdivided into individual program components, each with its own set of requirements and procedures. An example of a list of IH programs is provided in Table 27–B. These requirements identify what should be done, how it should be done, who should do it, and how often. Besides effectively communicating the program to the rest of the organization, it also documents how the organization identifies and deals with industrial hygiene related issues. This information can be

Table 27–A. ***Summary of Criteria and Activities for an Industrial Hygiene Program***

Program Element Activity	*Activity*	*Measurement Criteria*	*Goal*
Policy	Write, prepare/present for management acceptance	Is policy complete? Is policy understood and supported by management/ employees? Does policy carry authority needed for implementation?	An accepted and working policy that clearly states the scope, responsibilities and authority of the program.
Education	New employee orientation Periodic information and education sessions Written safety and health guidelines Posting of dangerous areas Labeling of materials handled by employees	No. of educational materials produced and distributed Increase in employee knowledge of safety and health issues Employee avoidance of hazards	Increased employee awareness of health and safety in the workplace.
Health hazard recognition	Plant survey Chemical inventory Process and equipment review Health hazard review procedures Process change review procedures	No. of surveys Completion and procedure update Procedures and staff in place for review, etc.	Identify all present and potential hazards in the workplace.
Health hazard evaluation	Environmental monitoring (area, personal) Sample analysis Statistical analysis of data Biological monitoring Records of data Establishment of criteria	No. of samples collected No. of analyses performed Statistical significance of sample data Well-documented recordkeeping system Established criteria for each stress	Measure and quantitatively evaluate stresses and hazards, determine their impact upon the work environment.
Health hazard control	Design and/or recommend administrative and engineering controls Procedural mechanism for implementing controls Procedural mechanism for including controls as a part of planning for new processes and changes in existing processes Administrative review of rejected procedures	Controls implemented and working Administrative procedures in place	Control or reduce to the lowest level all potential workplace hazards.
OSHA compliance	Review all present and future regulations, standards Determine level of compliance obtained via compliance inspections	No violations present Program positioned to comply with regulations	Complete compliance with all laws, regulations, standards, etc.

(Printed with permission from Toca FM. Program evaluation: Industrial hygiene. *AIHAJ* 42:213–216, 1981.)

used to demonstrate compliance and commitment to employee health and safety during an internal or external audit or inspection. More importantly, written procedures provide measurable performance guidelines for worker protection and helps assure continuity from one program owner to another.

Hazard Recognition and Evaluation

Hazard recognition is the identification of workplace occupational health hazards. These include chemical, physical, and biological hazards. The identification depends on the professional judgment of the industrial hygienist, based on information gathered during walk-through surveys, inspections, interviews with employees and management, and review of applicable documentation such as purchases of new equipment and chemicals. Hazard evaluation is the determination of whether worker exposure to these environmental hazards is acceptable, or if additional engineering, administrative, or work practice control measures are necessary. Knowledge of acceptable exposure limits such as those set by OSHA or the American Conference of Governmental Industrial Hygienists is vital to ensuring a proper assessment of a potential health risk.

Table 27–B. *Typical Subcategories of an Industrial Hygiene Program*

A. Health and Safety Policy
B. Management Responsibilities
C. Hazard Communication
D. Chemical and Equipment Authorizations
E. Exposure Assessment
F. Industrial Ventilation
G. Indoor Air Quality
H. Ergonomics
I. Ionizing Radiation
J. Non-ionizing Radiation
K. Hearing Conservation
L. Toxic Gases
M. Biohazards
N. Personal Protective Equipment
O. Accident Investigation
P. Emergency Response
Q. Safety Inspections and Audits

Various industrial hygiene systems have been developed which systematically and comprehensively identify and evaluate occupational health hazards at a facility. This includes a program to ensure the use of calibrated equipment, accepted analytical techniques, and accredited or certified laboratories qualified to analyze IH samples. One example is an approach using qualitative and quantitative exposure assessments, which is an objective determination of potential exposures based on an evaluation of the process, chemicals, physical agents, work practices, and controls.

➢ The goal of an exposure assessment program is to determine the potential and actual exposures in order to minimize risks of adverse effects impacting employee health. In addition, this program helps demonstrate compliance with legal and internal company requirements and provides an avenue for employee communication regarding the safety of their work environment. There are numerous techniques for conducting these assessments, ranging from a response to employee complaints to the more proactive method of an exposure assessment strategy. The American Industrial Hygiene Association (AIHA), describes such a strategy in their publication, *A Strategy for Assessing and Managing Occupational Exposures.* A diagram in Figure 27–1 illustrates the steps in the process. The assessment begins by gathering information on the characteristics of the workplace, workforce, and the chemical, physical, and biological agents (Mulhausen & Damiano, 1998):

➢ *Workplace characterization* is a description of the processes and operations in the workplace, with particular attention paid to those areas with potential exposure to an environmental hazard (Figure 27–2).

➢ *Work force characterization* groups and describes employees with similar work duties or job classifications (Figure 27–3).

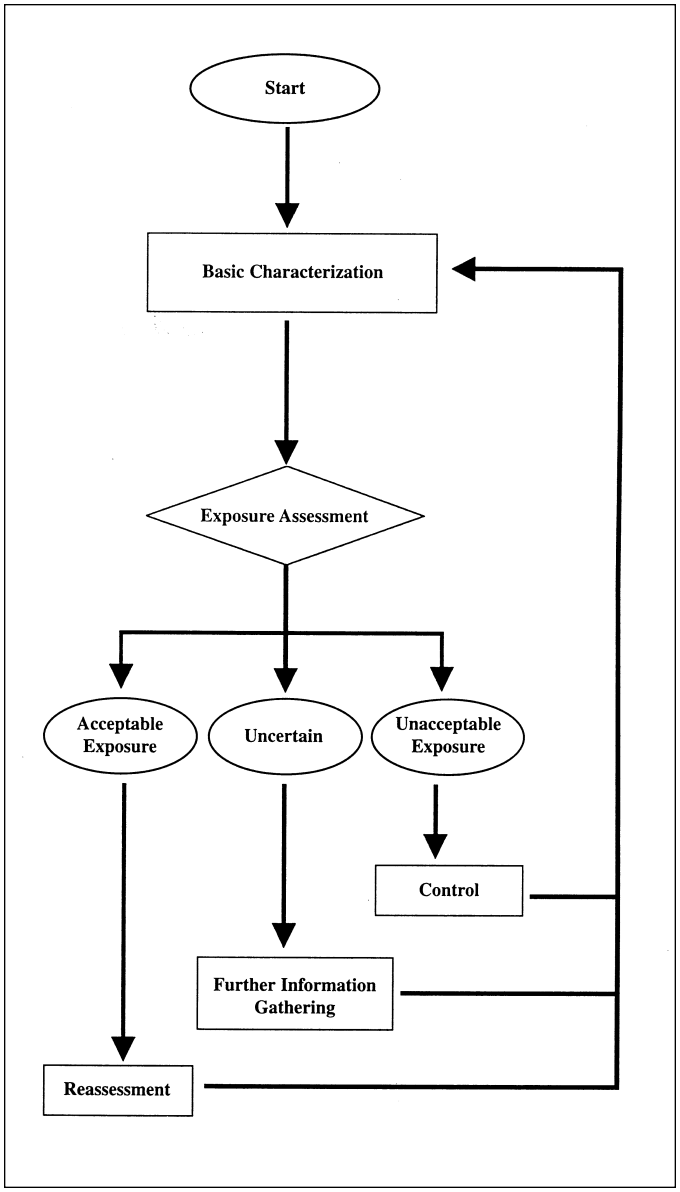

Figure 27–1. A strategy for assessing and managing occupational exposures. (Reprinted with permission from Mulhausen J, Damiano J, eds. *A Strategy for Assessing and Managing Occupational Exposures.* Fairfax, VA: AIHA, 1998.)

➢ *Agent characterization* is the construction of an inventory of environmental agents and includes a description of their potential adverse health effects, how they are used, how much is used, and their physical properties.

Once the environment is characterized, the evaluation step begins. This usually starts with a grouping of employees into similar exposure groups, or SEGs. This is done to apply monitoring data to employees who were not directly monitored, but who might be represented by the samples collected. Workers in SEGs are those who can be expected to have the same or similar exposure profiles to an environmental agent based on the information gathered during the workplace, work force, and agent characterizations.

Sodium Chloride Production Plant

Process Description

Chlorine gas is received directly by pipeline from an adjacent vendor plant; the gas arrives at a line pressure of 200 psig, passes through a pressure letdown valve, and enters T-1 column at 20 psig. 25% hydrogen peroxide is received in tank cars and is diluted with process water to 19% before being pumped to T-2 column. In Columns T-1 and T-2, chlorine and hydrogen peroxide go through a counterflow reaction to produce a 29% aqueous hydrochloric acid (HCl) solution; trace amounts of chlorine are vented to the atmosphere at T-2 column.

A 50% sodium hydroxide solution is received by pipeline from an adjacent vendor plant and is stored in S-2 tank before being pumped to R-1 reactor. From T-2 column, the HCl solution is pumped to R-1 reactor to react with the caustic and produce a 35% sodium chloride solution (brine). The brine is contacted with heated air in F-1 fluid bed dryer to make sodium chloride granules with a size range of 100 to 200 microns. The finished product is transferred to storage hopper H-1.

The industrial grade sodium chloride is packaged in 50-pound bags and palletized in 1,000-pound loads. Each pallet is film-wrapped in an automatic shrink-film apparatus. A tow motor is used to move pallets from the bagging station to the shrink-film station and then to the warehouse. At the warehouse, the tow motor is also used to load the wrapped pallets into truck trailers.

The plant is currently producing about 50 million pounds per year of industrial grade sodium chloride; the plant operates about 300 days per year with the remaining time used for scheduled maintenance work. On a daily basis, the plant receives about 53 tons of chlorine gas, 120 tons of caustic solution, and 306 tons of hydrogen peroxide solution.

Figure 27–2. Process description developed for an example of an exposure assessment strategy for a hypothetical sodium chloride production facility. Development of such a workplace description is fundamental to completing the workplace characterization portion of the basic characterization step of the strategy. (Reprinted with permission from the American Industrial Hygiene Association. *A Strategy for Occupational Exposure Assessment*. Fairfax, VA: AIHA, 1991.)

The evaluation of each hazard listed for a homogeneous group involves two stages. First, a subjective determination is made as to whether the exposure to each environmental agent listed for a homogeneous exposure group is low, moderate, high, or very high relative to an exposure limit. This determination is based on such factors as the frequency and duration of the exposure, estimated exposure level, and the severity of the health effects resulting from the exposure. Second, the exposures are monitored and the results compared against established exposure limits. In the first phase, the potential exposures which are rated very high are monitored first, and those rated low are monitored last. Sampling plans should specify the number and duration of samples to be taken, in order to ensure true representation of employee exposures. Table 27–C illustrates a sampling strategy developed for a fungicide used in the lumber industry.

A written procedure for sampling methods is necessary to ensure that samples are collected in a proper, consistent, and professionally accepted manner. For example, the National Institute for Occupational Safety and Health publishes the *Manual of Analytical Methods*. Procedures should include information on calibration, field use and maintenance of the equipment, quality control, and use of approved or accredited laboratories. In addition, procedures should be developed to ensure that employees receive copies of the monitoring results and are afforded the opportunity to observe monitoring.

A periodic reevaluation of exposure assessments should be done to determine whether conditions have changed significantly. The frequency and scope of the reevaluation depend on the severity of the hazards. A new assessment should be done if a new process or potentially hazardous agent is introduced into the workplace.

Hazard Control

If exposure levels are judged to be unacceptable based on established limits or professional judgment, measures must be taken to eliminate or reduce the exposure. The industrial hygiene program includes specification of control measures, whether included in its documentation (e.g., exhaust ventilation, hearing conservation, respiratory protection, hazard communication, ergonomics programs) or as a result of recommendations following surveys and assessments. Controls may be substitution, engineering, administrative, personal

Job Descriptions

Operations Personnel

Superintendent: Spends about 10% of time in general process areas observing operations, checking equipment conditions, and supervising maintenance work; remaining time spent in office environments on administrative, supervisory, and planning activities.

Engineer: Spends about 35% of time in general process areas troubleshooting process problems, supervising maintenance work, and collecting industrial hygiene samples; remaining time spent on training, computer program development, and other office activities.

Shift Supervisor: Spends about 5% of time in general process areas checking on operations and investigating possible process problems; remaining time spent in control room areas overseeing operation of the acid, reactor, and dryer systems.

Relief Operator: Spends about 20% of time covering each of the shift supervisor, acid system operator, reactor system operator, and assistant operator job classifications; remaining time spent on various maintenance activities.

Operator, Acid System: Spends about 40% of time in the HCl production areas checking equipment, adjusting flows, and preparing equipment for maintenance; about 10% of time is spent collecting process samples and another 25% is spent in lab running analyses on all process samples; remaining time is spent in control room areas.

Operator, Reactor System: Spends about 60% of time in the reactor and fluid bed dryer areas checking equipment, adjusting flows, and preparing equipment for maintenance. About 10% of time is spent collecting process samples; remaining time is spent in control room areas.

Assistant Operator: Spends about 50% of time at bagging station loading product into 50-pound bags; another 25% of time is spent using tow motor to move pallets to and from the warehouse and to load product into truck trailers; about 5% of time is spent loading product directly from storage into hopper cars; remaining time is spent in control room areas.

Electrical/Instrument Technician: Spends about 5% of time in the HCl production areas maintaining and calibrating in-line chlorine analyzer; approximately 25% of time is spent in general process areas and switchgear room maintaining electrical equipment; about 50% of time is spent in control room or maintenance shop repairing or modifying process control instruments; remaining time is spent on office activities.

Figure 27–3. Sample job description for operations personnel in a hypothetical sodium chloride production facility. The descriptions were developed to fulfill the work force characterization requirements of the basic characterization step of the strategy and to be used as an approach for determining homogeneous exposure groups. (Reprinted with permission from the American Industrial Hygiene Association. *A Strategy for Occupational Exposure Assessment*. Fairfax, VA: AIHA, 1991.) *(Continues)*

protective equipment, or a combination of these methods. In almost every case, substitution (elimination) and engineering controls are preferred over personal protective equipment, which should be the last choice for control measures. An effective program is one that considers the use of appropriate control measures during the design of new processes or equipment before use in production. Process (including consideration for chemical use), facilities, and equipment design reviews are usually more protective and the most cost-effective methods for instituting controls measures. Maintenance of operational controls should be documented along with clearly assigned responsibilities.

Employee Training and Education

The industrial hygienist plays an important role in employee training programs. Employees need information and training so that they can be actively involved in protecting their health. Done properly, this can be one of the most effective control measures since it provides employees with real time understanding of the potential hazards in their work and the corrective actions to be taken to prevent adverse affects. Training has become a standard part of most OSHA regulations. In most categories listed in Table 27–B, there is an element of training, education, and awareness ranging from labels and postings to classes and certifications. The method (e.g., labeling versus

Pipe Fitter/Welder: Spends about 30% of time in maintenance shop on welding work associated with process piping and equipment repairs; about 40% of time is spent in general process areas removing or replacing piping and process equipment; remaining time is spent in shop office or control room.

Utility Mechanic: Spends approximately 20% of time helping process operators with preparation of equipment for maintenance; about 50% of time is spent repairing equipment in shop; another 10% of time is spent in general process areas making minor repairs to process equipment; remaining time is spent in shop office or in control room.

Personnel Roster

Name	*Company ID No.*	*Job Classification*	*Job Code*
J. R. Smith	20066	Superintendent	0062
M. C. Jones	10081	Engineer	0085
	10018	Shift Supervisor	0105
	10025	Shift Supervisor	0105
	10038	Shift Supervisor	0105
	10040	Shift Supervisor	0105
	10019	Relief Operator	0121
	10050	Relief Operator	0121
	10029	Operator, Acid System	0123A
	10042	Operator, Acid System	0123A
	10066	Operator, Acid System	0123A
	10071	Operator, Acid System	0123A
	10021	Operator, Reactor	0123R
	10048	Operator, Reactor	0123R
	10052	Operator, Reactor	0123R
	10065	Operator, Reactor	0123R
	10088	Assistant Operator	0129
	10096	Assistant Operator	0129
	10099	Assistant Operator	0129
	10100	Assistant Operator	0129
	10044	Elec/Instr Technician	0210
	10030	Pipe Fitter/Welder	0230
	10061	Utility Mechanic	0255
	10078	Utility Mechanic	0255

Figure 27–3. *(Concluded)*

classroom training) chosen for employee education depends on the type and degree of the hazard, which should be part of the assessment and recommendation provided by the industrial hygienist. The following summary was taken from *Training Requirements in OSHA Standards and Training Guidelines* (OSHA 1992) and provides a guidance for establishing training.

Determine if Training is Needed. Determine whether a problem can be solved by training. Training can address lack of knowledge or incorrect knowledge, but cannot effectively address lack of motivation or attention to the job.

Identify Training Needs. Determine what is expected of the employee and what kind of training is needed to accomplish this. Consult with the safety committee and employees in the area to get their ideas to help make the training more effective and tailored to their needs.

Identify Goals and Objectives. Instructional objectives tell the employee what is expected of them. Clear and measurable objectives must be established before training begins. Using specific, action-oriented language, the instructional objectives should describe the preferred practice or skill and its observable behavior.

Developing Learning Activities. Learning activities enable employees to demonstrate that they have acquired the

Table 27–C. ***Proposed Strategy for Assessing Exposures***

- Identify all work sites using antisapstain agent of interest.
- Ask managers at each work site to tally number of workers in each of five strata:
  - Graders or lumber pullers who handle wet wood
  - Elevator or forklift dip-tank operators
  - Others who handle wet wood
  - Maintenance workers who operate the fungicide supply system or maintain machinery downstream of treatment
  - Employees who handle dry treated lumber
- Randomly select 30 workers from complete population of each stratum.
- Contact each worksite whose workers have been selected for exposure measurement.
- Randomly select two measurement days within a 1-year period for each selected worker.

desired skills and knowledge. The learning situation should simulate the actual job as closely as possible using participatory training techniques such as hands-on work or opportunities to engage in case studies.

Conducting Training. The training should be presented so that its organization and meaning are clear to the employees. An effective program allows employees to participate in the training process and to practice their skills or knowledge.

Evaluation of Program. To make sure that the program is accomplishing its goals, an evaluation of the training is necessary. Methods of evaluation include student opinions surveys, supervisor's observations, and student tests.

Improving the Program. If the training did not give the employees the necessary level of knowledge and skills, then the training program must be revised. It may be necessary to repeat the steps in the training process.

Document the Training. A written record is needed to document how identified training needs have been met. It should include attendance records, course outlines or lesson plans, student exams, and handout materials.

Documentation/Recordkeeping

Industrial hygiene related documentation must be maintained. The decisions made by industrial hygienists can have legal as well as regulatory consequences. OSHA 29 *CFR* 1910.20 mandates that exposure records must be maintained for at least 30 years. The documentation is needed to demonstrate that the work has been conducted in accordance with professional standards, and it may be useful for future industrial hygiene or medical evaluations. Documentation of programs such as training, respiratory protection programs, and hearing conservation programs must be maintained as well. Many organizations have developed their own forms, recordkeeping procedures, and data bases to efficiently handle the large amount of documentation that is generated.

Employee Involvement

Effective health and safety programs includes a commitment by the employer to encourage employee involvement in decisions that affect worker safety and health. There are many methods and those selected have much to do with the culture of the company and/or location. One approach is the use of safety and health committees. Also common is an employee suggestion program which provides timely feedback of concerns and suggestions without fear of reprisal. At a minimum, employees should be encouraged to participate by reporting unsafe work conditions and signs or symptoms related to work with hazardous agents so that proper evaluations are conducted and corrective actions, if any, are taken.

Program Evaluation and Program Audit

Methods must be developed to periodically evaluate the effectiveness of the industrial hygiene program. Audits are commonly used to determine whether the elements of the program have been implemented in accordance with established procedures, and whether these procedures have been effective in achieving their goal. Auxiliary benefits include a reassessment of priorities and resources allocation, and an increased awareness of and commitment to the program by management.

An audit is usually requested by senior management and is done by a health and safety specialist or a team of specialists from outside the facility being audited. This ensures the objectivity of the auditor and also provides fresh insight into the program. The audit team is usually from the corporate or headquarters staff, but in some cases, an independent third party such as an insurance loss control representative or independent consultant is used. Self-audits, though not independent, can nonetheless be useful evaluation tools.

The scope of an audit depends on the time and resources devoted to it. For a small facility, a comprehensive audit of all industrial hygiene program components can be easily accomplished, whereas a large facility may require more time, resources or a reduced scope. For this reason, larger organizations often concentrate their audits on high-priority items.

Auditors prepare for an audit by researching the requirements of the program components and developing a plan to evaluate compliance. Audit checklists are often developed to guide and focus the collection of information. Extensive lists are usually developed for each program component. In the interest of time, these are often sent in advance to the facility. This allows management time to collect the necessary written documentation, schedule interviews with key personnel, and if necessary, ensure that certain processes or tasks of concern will be operational during the audit.

There are generally five phases to an audit. It usually begins with an opening conference with the management of the facility, during which the purpose, scope, and schedule of the audit is discussed. Then there is the information gathering stage. Next, the information is analyzed, key facts confirmed, and contradictions resolved. During this phase the auditor can usually generalize from specific situations to underlying program deficiencies. Then the auditors present their findings to management during a closing conference, at which time any remaining concerns can be discussed. Finally, a report of findings is issued.

Much of the value of the audit is lost if there is no established mechanism for follow-up, which can be accomplished with follow-up audits and/or by requiring the facility to develop written action plans and submit periodic progress reports.

ORGANIZATIONAL RESPONSIBILITIES

Organizational responsibilities for the program should be clearly defined. Industrial hygiene may be part of the safety department or another department, or it may be a department by itself. There should be a statement, such as policy or other document, that clearly communicates health and safety responsibilities including where the industrial hygiene program gets its authority and to whom it reports.

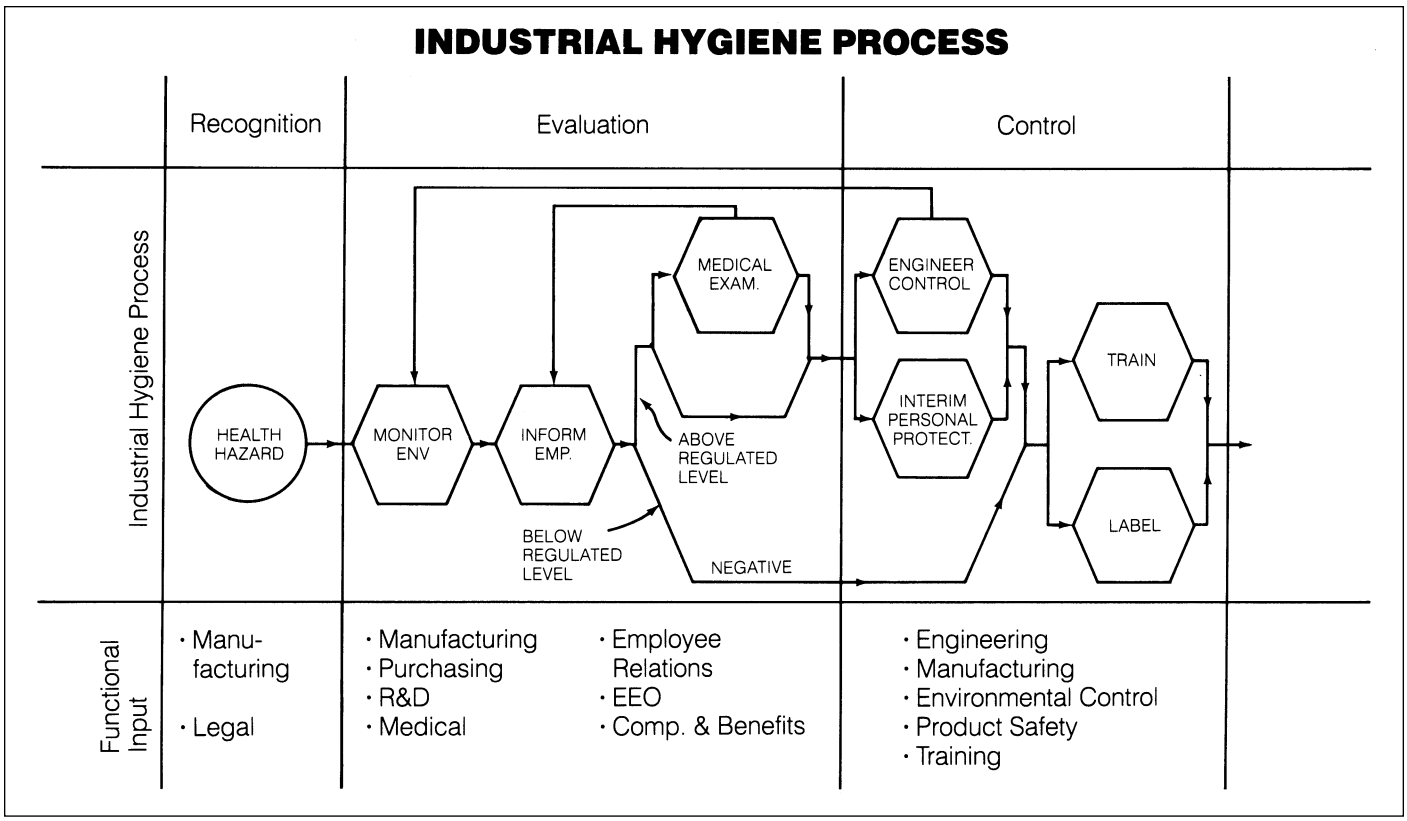

Figure 27–4. The Industrial Hygiene Process. (Adapted with permission from Bridge DP. Developing and implementing an industrial hygiene and safety program in industry. *AIHA Journal* 40:255–263, 1979.)

The success of safety and industrial hygiene programs requires the cooperation of many organizations and groups. Figure 27–4 illustrates how each step of the industrial hygiene process of recognition, evaluation, and control requires the expertise of many other functional areas. The role of all areas need not be defined in the written program, but the roles of the main players must be in writing in order to avoid confusion and ensure efficient implementation of the program.

Medical Program

Modern occupational health programs are ideally composed of elements and services designed to maintain the overall health of the work force and to prevent and control occupational and nonoccupational diseases and injuries. A large corporation may have a full-time staff of occupational health physicians and nurses, equipped with a model clinic. A small manufacturer, on the other hand, may rely on a nearby occupational health clinic.

Medical programs usually offer the following services:

- ➢ Health examinations
- ➢ Diagnosis and treatment
- ➢ Medical recordkeeping
- ➢ Medical or biological monitoring
- ➢ Health education and counseling
- ➢ Wellness activities
- ➢ Medical case management

The industrial hygiene program should provide information, such as an exposure assessment or the work conditions in the facility, to the medical department. To do an effective job, the health professional must have a good understanding of what is made, how it is made, the potential safety and health hazards associated with these manufacturing processes, and the physical requirements of the various jobs. This information is necessary to adequately perform preplacement and periodic medical examinations, to detect conditions that might be work related, and to conduct health education programs

The medical department works with the industrial hygiene department in developing adequate, effective measures to prevent exposure to harmful agents. They periodically examine employees who are working with or exposed to hazardous agents or materials, and, if warranted, restrict employees from further exposure and notify the industrial hygiene staff of their findings. Maintenance of medical records associated with all medical examinations and findings is the responsibility of medical personnel. It is also common for the medical staff and IH to conduct joint surveys such as an ergonomic assessment.

Engineering

Engineering professionals are involved with the design and modification of manufacturing processes and facilities sup-

porting these processes. Because these processes may introduce health and safety hazards into the workplace, engineers must coordinate their plans with the safety professional and the industrial hygienist. It costs much less to anticipate and eliminate a hazard in the planning stage than it does to manage it afterward. In cases where there is an existing hazard, the industrial hygienist must work with the engineer to develop control methods to reduce or eliminate the hazard.

Safety

The safety professional and industrial hygienist are concerned with the same goal: maintaining a safe and healthful workplace. Because safety programs tend to be older and more established than industrial hygiene programs, industrial hygiene is often part of the safety department.

The safety professional's main responsibility is to run an effective safety program. An effective safety program lends credibility and builds support for all health and safety related work at the facility. It also enhances the safety program's recognition of industrial hygiene issues and will work them into such safety activities as workplace inspections, accident investigations, and accident trend analysis and make appropriate referrals to the industrial hygienist. If industrial hygiene staffing is limited, safety professionals may accept responsibility for the implementation of the industrial hygiene program at their facility.

Purchasing

The purchasing department has the responsibility to ensure that only equipment and material approved by the industrial hygiene, safety, environmental, or other responsible reviewing organization are purchased. Purchasing should obtain material safety data sheets for all chemicals purchased.

General Manager

General managers (also known by such titles as location managers and operations managers) have the ultimate responsibility for the industrial hygiene program and the safety of their employees at their facilities. They must ensure that their facilities comply with applicable corporate policies and government regulations by providing the necessary resources and support that they need to be successful.

Supervisor

The supervisor is a key person in the implementation and maintenance of safety and health requirements on a day-to-day basis. Their responsibilities include setting a good example, ensuring that safety and health rules are followed, ensuring that employees are provided training concerning potential safety and health hazards and control measures associated with their jobs, ensuring that all necessary personal protective equipment is provided and used, ensuring that employees receive all required medical examinations, and promptly reporting any operation or condition that might present a hazard to employees.

Employees

Employees have the responsibility to perform their work in a manner that ensures their own personal safety as well as the safety of fellow employees. Employees must notify their supervisor immediately of hazardous work conditions or work practices, observe all safety and health rules, properly use and maintain personal protective equipment and other safety devices, maintain their work area in a neat and clean manner, and immediately report all accidents and near-miss incidents.

Safety and Health Committee

The safety and health committee(s) provides a forum for securing cooperation, coordination, and exchange of ideas among those groups involved in the safety and health program. It typically has three major functions: It examines company safety and health issues and recommends changes in practices or policies to management, conducts periodic workplace inspections, and evaluates and promotes interest in the program. It also provides a means of involving employees in the program. Joint management-labor health and safety committees are often used if the employees are represented by a union. At the committee meeting, key industrial hygiene program matters should be discussed and policies formulated.

SUMMARY

To accomplish the goal for preventing occupational illness and injury, there must be an effective industrial hygiene program. It requires the cooperation of employees and all levels of management. The program consists of a written program and policy statement, hazard identification, hazard evaluation and exposure assessment, hazard control, employee training and involvement, program evaluation and audit, and documentation/recordkeeping. Each component must be periodically evaluated to determine continuing effectiveness.

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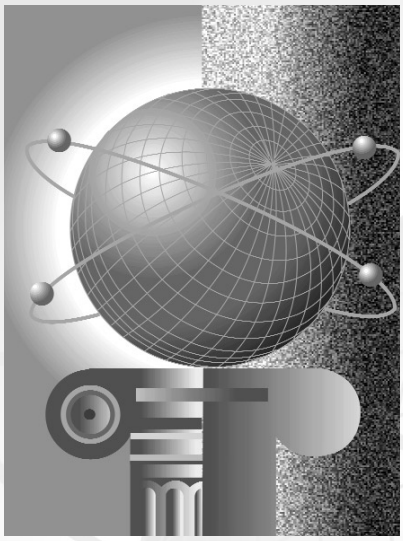

Government Regulations and Their Impact

Part VII

Chapter 28

Government Regulations

revised by Gabriel J. Gillotti, PE

Before 1970, government regulations of safety and health matters were largely the concern of state agencies. There was little uniformity of application of codes and standards from one state to another and almost no enforcement proceedings were undertaken against violators of those standards. Some states adopted as guidelines the Threshold Limit Values® (TLVs) for exposure to toxic materials as recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). However, enforcement of those guidelines was minimal.

The federal government had some safety and health standards for its contractors and for the stevedoring industry. Enforcement of those standards rested with the Bureau of Labor Standards in the U.S. Department of Labor. Although there were thousands of federal contractors, inspection and enforcement activities were restricted by the U.S. Department of Labor's limited budget and staff.

In 1970 and 1977, Congress enacted two new safety and health laws. These legislative efforts continue to have a significant impact on industrial hygiene activities in the United States. These laws are as follows:

- *Public Law 91–596, December 29, 1970: the Occupational Safety and Health Act of 1970, popularly known as OSHAct*
- *Public Law 91–173, November 9, 1977: the Federal Mine Safety and Health Act of 1977*

THE OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

The Occupational Safety and Health Administration (OSHA) came into official existence on April 28, 1971, the date the OSHAct became effective. This organization was created by the Department of Labor to discharge the responsibilities assigned to it by the Act. (See Chapter 29, History of the Federal Occupational Safety and Health Administration.)

Major Authorities, Functional Areas, and Responsibilities

The OSHAct grants the secretary of labor the authority to promulgate, modify, and revoke safety and health standards; to conduct inspections and investigations and to issue citations, including proposed penalties; to require employers to keep records of safety and health data; to petition the courts to restrain imminent danger situations; and to approve or reject plans from states proposing to assume jurisdiction from federal OSHA over their private sector industries and state and local governments.

The secretary of labor's authority regarding federal agencies includes the right to inspect agency worksites based on compensation data and to issue notices of violation when appropriate. Annual reports are filed with the respective agency heads, citing the deficiencies and positive elements of the agency's program. Under Executive Order 12196, the secretary must ensure that all federal agencies comply with OSHA's standards.

The act authorizes the secretary to have the Department of Labor train personnel in the duties related to their responsibilities under the act and, in consultation with the U.S. Department of Health and Human Services (DHHS), to provide training and education to employers and employees. Other responsibilities of the DHHS are delineated in sections 20, 21, and 22 of the OSHA law are quite extensive. The section 20 provision of the law also directs the DHHS to delegate its statutory functions to the National Institute for Occupational Safety and Health (NIOSH), whenever feasible. NIOSH is an agency within DHHS. The National Institute for Environmental Safety and Health (NIESH) is also in the DHHS and does grant funds to organizations interested in training employees and others on health hazards, primarily in hazardous waste handling. The secretary and his or her designees are authorized to consult with employers, employees, and organizations regarding prevention of injuries and illnesses. Under the law, federal OSHA cannot conduct onsite consultation, only those with whom they contract under section 7{c} or the state OSHA agencies can consult. The secretary of labor, after consulting with the secretary of the DHHS, may grant funds to the states to identify program needs and plan development, experiments, demonstrations, administration, and operation of programs. In conjunction with the secretary of the DHHS, the secretary of labor is charged with developing and maintaining a statistics program for occupational safety and health.

Major Duties Delegated by the Secretary of Labor

In establishing the Occupational Safety and Health Administration, the secretary of labor delegated to the assistant secretary for occupational safety and health the authority and responsibility for the safety and health programs and activities of the Department of Labor, including responsibilities derived from the following legislation:

- Occupational Safety and Health Act of 1970
- Walsh-Healey Public Contracts Act of 1936, as amended
- Service Contract Act of 1965
- Public Law 91-54 of 1969 (Construction Safety Amendments)
- Public Law 85-742 of 1958 (Maritime Safety Act)
- National Foundation on the Arts and Humanities Act of 1965

The delegated authority includes responsibility for organizational changes, for coordination with other officials and agencies with responsibilities in the occupational safety and health area, and for contracting.

At the same time, the commissioner of the Bureau of Labor Statistics was delegated the authority and given the responsibility for developing and maintaining an effective program for collection, compilation, and analysis of occupational safety and health statistics, providing grants to the states to assist in developing and administering the statistics programs, and coordinating functions with the assistant secretary for occupational safety and health.

The solicitor of labor is assigned responsibility for providing legal advice and assistance to the secretary and all officers of the Department of Labor in the administration of statutes and executive orders relating to occupational safety and health. In enforcing the act's requirements, the solicitor of labor also has the responsibility for representing the secretary in litigation before the Occupational Safety and Health Review Commission and, subject to the control and direction of the attorney general, before the federal courts.

The Department of Labor regulations dealing with OSHA are published in Title 29 of the *Code of Federal Regulations* (*CFR*) as follows:

- 29 *CFR* 1902 to 1908—Enforcement and Consultation Regulations
- 29 *CFR* Part 1910—General Industry Standards
- 29 *CFR* 1911–1925—Miscellaneous Regulations
- 29 *CFR* Part 1915—Shipyard Standards
- 29 *CFR* Part 1917—Marine Terminal Standards
- 29 CFR Part 1918—Longshoring Standards
- 29 *CFR* Part 1926—Construction Standards
- 29 *CFR* 1928—Agriculture Standards

General Duties and Obligations

OSHAct sets out two duties for employers and one for employees. The general duty provisions are as follows:

- Each employer shall furnish to each employee a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm to the employee.
- Each employer shall comply with occupational safety and health standards under the act.
- Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to the act that are applicable to his or her own actions and conduct.

The significance of the General Duty Provision (section 5[a]) is that it authorizes the enforcement of a recognized

industry safety or health standard when identified hazards are not covered by an existing OSHA standard. Only violations viewed as serious may be cited under the general duty clause. This interpretation of the general duty clause for providing a safe and healthful working environment adds new dimensions to the protection of employee health.

Key Provisions

Some of the key provisions of the act are as follows:

- ➢ Assure, insofar as possible, that every employee has safe and healthful working conditions.
- ➢ Require employers to maintain accurate records of exposures to potentially toxic materials or harmful physical agents that are required, under the various safety and health standards, to be monitored or measured, and inform employees of the monitoring results.
- ➢ Provide for employee walkaround or interview of employees during the inspection process.
- ➢ Provide procedures for investigating alleged violations at the request of any employee or employee representative, issuing citations, and assessing monetary penalties against employers.
- ➢ Empower the secretary of labor (through the Occupational Safety and Health Administration) to issue safety and health regulations and standards that have the force and effect of law.
- ➢ Provide for establishment of new rules and regulations for new or anticipated hazards to health and safety (section 6[b] of OSHAct).
- ➢ Establish a National Institute for Occupational Safety and Health (NIOSH), with the same right of entry as OSHA representatives, to undertake health studies of alleged hazardous conditions and to develop criteria to support revisions of health standards or recommendations to OSHA for new health standards.
- ➢ Provide up to 50/50 funding with states that wish to establish state programs that are at least as effective as the federal program in providing safe and healthful employment (section 18 of OSHAct).
- ➢ Provides funds under section 7{c} to state governments and other entities for the purpose of authorizing and enabling them to conduct onsite consultations for employers upon request.

STATE PLANS

As provided for under section 18 of OSHAct, a state agency can assert jurisdiction under state law over safety and health if a state plan that meets the criteria set forth in section 18(c) is submitted for approval by federal OSHA.

As of this date, there are 23 approved state plans as well as plans from Puerto Rico and the Virgin Islands. Federal OSHA officers submit periodic written reports to the assistant secretary of labor addressing the quality of state performance as measured by established criteria. The data are gathered and analyzed on an ongoing basis, dialogue is carried on, and meetings are held routinely with state representatives to gather data and resolve problems identified by the measures.

After the plan is approved, the administering agency must promulgate standards that are at least as effective as (ALAEA) the federal standards, not only at the time of approval but on a continuing basis. Although most states adopt the federal standards verbatim, some modify and expand the federal standards to make them more applicable to the state's industries. State compliance policies must be ALAEA federal penalty-determining formulas and inspection procedures.

To ensure that the level of protection across states is consistent with the intent of OSHAct, the regulations also provide for the filing of complaints against a state program's administration (CASPA). Any person can call on federal OSHA to investigate any state program deficiency that may render the state program less effective than the federal program. The filing of a CASPA is a rare occurrence but it acts as a monitoring tool along with the performance measures.

There is a provision in the statute for withdrawing a deficient state plan approval, but there has not been adequate cause to do so to date.

In lieu of withdrawing a state plan approval, there are other alternatives that may achieve the same purpose while keeping the plan intact in the interest of maintaining continous employee coverage. For example, when a disaster occurred in one state, the program deficiencies that allegedly contributed to the incident in the form of inadequate enforcement were identified and discussed by the responsible federal and state OSHA officials and a satisfactory resolution was implemented. The federal staff assumed jurisdiction in the state for a limited time, but the state officials succeeded in increasing their staff and modifying their enforcement policies until both parties agreed that the probability of such an incident recurring had been reduced substantially.

OSHA STANDARDS

Health standards are promulgated under the OSHAct by the Department of Labor with technical advice from NIOSH. A review of OSHA's standard-setting process will be helpful in understanding how regulations are derived.

Most of the safety and health standards now in force under OSHAct for general industry were promulgated 30 days after the law went into effect on April 28, 1971, as 29 *CFR* Part 1910 of Department of Labor regulations (Title 29). They represented a compilation of material authorized by the act from existing federal, state, and consensus standards (ANSI and NFPA). These, with some amendments, deletions, and additions, remain the body of standards under the OSHAct.

The act prescribes procedures for use by the secretary of labor in promulgating regulations. It is of special interest that the 1968 ACGIH Threshold Limit Values® for expo-

sures to toxic materials and harmful agents have been adopted in the regulations and have the effect of law. Although procedures are given for measuring exposure levels to specific materials and agents in the standards promulgated by the Department of Labor, professional skills and judgments are still required in applying the intent of the many aspects of the act.

Categories

The OSHA standards consist of the following categories:

DESIGN STANDARDS

Examples of these detailed design criteria are the ventilation design details contained in section 1910.94 of the initial standards.

PERFORMANCE STANDARDS

Such standards are the Threshold Limit Values (TLVs®) of the ACGIH, which are contained in section 1910.1000. A performance standard states the objective that must be achieved and leaves the method for achieving it up to the employer.

VERTICAL STANDARDS

A vertical standard applies to a particular industry, with specifications that relate to individual operations. Section 1910.261 (subpart R) of the initial standards is in this category—it applies only to pulp, paper, and paperboard mills.

HORIZONTAL STANDARDS

A horizontal standard is one that applies to all workplaces and relates to broad areas, such as Sanitation (1910.141) or Walking and Working Surfaces (part 1910 subpart D).

Standards Development

The development of standards is a continuing process. NIOSH provides information and data about health and safety hazards, but the final authority for promulgation of the standards remains with the secretary of labor.

Section 6 of the OSHAct defines how safety and health standards are to be set. The secretary of labor promulgates standards "based upon research, demonstrations, experiments, and such other information as may be appropriate. In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest scientific data in the field, the feasibility of the standards, and experience gained in this and other health and safety laws. Whenever practicable, the standard promulgated shall be expressed in terms of objective criteria and of the performance desired" (section 6[b][5]).

There is a mechanism in the act (section 6[c]) by which the labor secretary can promulgate emergency standards if he or she believes the evidence supports it. Emergency health standards have been promulgated for asbestos, carcinogens, and acrylonitrile. Following the time period required by the act, these have then been followed by the public rule-making process with promulgation of final standards.

As mentioned earlier, the first health standards were the 8-hour time-weighted average (TWA) values of air contaminants from the 1968 ACGIH TLV list; they now have the force of legal requirements. Guidance for specific sampling strategies, medical surveillance, and protective measures were lacking. However, section 8(c)(3) of the OSHAct requires employers to measure contaminants, maintain records, and notify employees of overexposures and corrective action to be taken for all future health standards.

Because there has been a significant effort in the Department of Labor to increase the rate at which health standards are promulgated, NIOSH has prepared a number of criteria documents for use as a basis for various health standards. In turn, OSHA has proposed some health standards that include the areas of action described in section 8(c)(3).

For reference purposes, the indices of OSHA health standards are contained in subpart G—Occupational Health and Environmental Controls, subpart 1—Personal Protective Equipment, and subpart Z—Toxic and Hazardous Substances. Another standard of interest to health professionals is 29 *CFR* 1910.120, *Hazardous Waste Operations and Emergency Response.*

Other standards of interest to health professionals are 1910.20 *Access to Employee Exposure and Medical Records,* and 1910.132 *Personal Protective Equipment for General Industry.*

ACTION LEVEL

Of interest to the industrial hygienist is the action level concept. In 1976, OSHA defined the action level as typically one-half the permissible exposure limit (PEL). Where exposures reach or exceed the action level, additional requirements apply, including medical surveillance and a full air-monitoring program. Exposures to an airborne concentration above the PEL trigger still further requirements, including reduction of exposures to (or below) the PEL by means of engineering controls supplemented by work practice controls, use of specified respirators, and use of other appropriate protective clothing and equipment.

EMPLOYEE PROTECTION

OSHA decided as a policy matter that the action level, which triggers the measurement requirements, be set below the PEL to better protect employees from overexposure. OSHA reasoned that this method was the most reasonable approach to a recurring problem, that is, how to provide the maximum employee protection necessary with the minimum burden to the employer. Thus, where the results of employee exposure measurements demonstrate that no employee is exposed to airborne concentrations of a substance in excess of the action level, employers are exempted from major provisions of the particular standard.

Table 28–A. ***Part 1910—Occupational Safety and Health Standards***

Subpart G—Occupational Health and Environmental Control	
1910.94	Ventilation
1910.95	Occupational noise exposure
1910.96	Ionizing radiation
1910.97	Nonionizing radiation
1910.98	Additional delay in effective date
1910.99	Sources of standards
1910.100	Standards organizations
Subpart Z—Toxic and Hazardous Substances	
1910.1000	Air contaminants
1910.1001	Asbestos
1910.1002	Coal tar pitch volatiles; interpretation of term
1910.1003	13 Carcinogens (4-nitrobiphenyl, etc.)
1910.1004	alpha-naphthylamine
1910.1005	Reserved
1910.1006	Methyl chloromethyl ether
1910.1007	3, 3'-Dichlorobenzidine (and its salts)
1910.1008	bis-chloromethyl ether
1910.1009	beta-naphthylamine
1910.1010	Benzidine
1910.1011	4-aminodiphenyl
1910.1012	Ethyleneimine
1910.1013	beta-propiolactone
1910.1014	2-acetylaminofluorene
1910.1015	4-dimethylaminoazobenzene
1910.1016	N-nitrosodimethylamine
1910.1017	Vinyl chloride
1910.1018	Inorganic arsenic
1910.1020	Access to employee exposure and medical records
1910.1025	Lead
1910.1027	Cadmium
1910.1028	Benzene
1910.1029	Coke oven emissions
1910.1030	Bloodborne pathogens
1910.1043	Cotton dust
1910.1044	1,2-dibromo-3-chloropropane
1910.1045	Acrylonitrile
1910.1047	Ethylene oxide
1910.1048	Formaldehyde
1910.1050	Methylenedianiline
1910.1051	1,3-Butadiene
1910.1052	Methylene chloride
1910.1096	Ionizing radiation
1910.1200	Hazard communication
1910.1201	Retention of DOT marketing, placards and labels
1910.1450	Occupational exposure to hazardous chemicals in laboratories

A duty to measure employee exposure and provide medical surveillance only when the employee exposure was equal to or greater than the PEL was rejected by OSHA as not providing sufficient protection for the exposed employees. Among other things, such a scheme would not protect employees from overexposure because the employer would have no way of knowing when airborne concentrations of a regulated substance approached the TWA. It is not possible to ensure that all exposures are within the permissible limits simply because sampling was done when an employee's exposure was at the PEL.

OTHER REQUIREMENTS

It has been determined, therefore, that three key duties should be triggered when an action level is reached—exposure measurement, medical surveillance, and employee training. All three actions are considered necessary by OSHA before employee exposure reaches the PEL. It is important to initiate measurement procedures periodically to monitor whether levels are approaching the PEL. One must do so to ensure that employee exposure does not exceed it. Similarly, employees should be screened for preexisting medical conditions and trained in suitable precautions against dangerous properties of the substance when there is some chance that their exposure will become significant.

OSHA has claimed that an alternative to establishing action levels would be to require medical and measurement procedures at any level of exposure, no matter how low. This alternative would burden employers unnecessarily because they would be required to implement medical and measurement provisions even where concentrations were so low that they presented no health problem.

The action level concept will, no doubt, continue to be a subject of discussion between the Department of Labor and practicing industrial hygienists. Some hygienists argue that a new permissible exposure level is created by arbitrarily setting 50 percent of the PEL as the action level. Some maintain that the blanket concept should not be imposed unless there is clear evidence of toxicity and there should be a differentiation between toxic substances and irritating substances. Others have stated that the action level approach used by OSHA is overly conservative because it assumes a single log-normal distribution for all cases and uses only one measured eight-hour TWA to estimate the mean of the distribution of other eight-hour TWAs.

Exposures at or just above the action level are not citable by OSHA, but failure to take the specified actions at the action level is citable.

HAZARD COMMUNICATION

The Hazard Communication Standard, 29 *CFR* 1910.1200, is one of OSHA's most significant standards. This standard was promulgated as a final rule on Nov. 25, 1983, and contains three important compliance dates. The first, Nov. 25, 1985, was the date on which all chemical manufacturers, importers, and distributors were required to label chemical shipping containers, assess chemical hazards, and provide material safety data sheets (MSDSs) to recipients of their chemicals.

The second compliance date, May 26, 1986, affected all employers covered by the standard under manufacturing division Standard Industrial Classification (SIC) codes 20 through 39. Beginning on this date, all covered employers

were to have had a written and operating hazard communication program that provides the necessary information and training to affected employees, including chemical container warnings, MSDSs, and other warnings.

On Aug. 24, 1987, OSHA expanded the scope of the hazard communication standard to include the nonmanufacturing sector. As of the third compliance date, May 24, 1988, all employers were to comply with the standard.

The intent of the hazard communication standard is to provide employees with information about the potential health hazards from exposure to workplace chemicals. The objective of the training is to provide employees with enough information to allow them to make more knowledgeable decisions with respect to the risks of their work and to impress on them the need for safe work practices. The standard requires the following employee training measures:

- ➢ Explanations of the requirements of the standard
- ➢ Identification of workplace operations where hazardous chemicals are present
- ➢ Knowledge of the methods and observations used to detect the presence of hazardous workplace chemicals
- ➢ Assessment of the physical and health hazards of those chemicals
- ➢ Warnings about hazards associated with chemicals in unlabeled pipes
- ➢ Descriptions of hazards associated with nonroutine tasks
- ➢ Details about the measures employees can take to protect themselves against these hazards, including specific procedures
- ➢ Explanation of the labeling system
- ➢ Instructions on location and use of material safety data sheets (MSDSs)
- ➢ Details on the availability and location of the hazardous material inventory, MSDSs, and other written hazard communication material

The standard applies to any chemical known to be present in the workplace that employees may be exposed to under normal conditions of use or may be exposed to in a foreseeable emergency. Pesticides, foods, food additives, cosmetics, distilled spirits, certain consumer products, and hazardous wastes are all covered under other federal legislation and, therefore, are exempt from this OSHA standard.

Numerous state and local governments have promulgated similar legislation, also known as right-to-know laws. These laws differ in some ways from the hazard communication standard.

In states with a federal OSHA enforcement program, the federal hazard communication standard preempts the state right-to-know law. This preemption was challenged once the standard went into effect, but the standard has not been modified as a result.

To date, the most frequently cited sections of the hazard communication standard are those dealing with the lack of a written hazard communication program, lack of a training program, and lack of labels on hazardous chemical containers.

The important role of the industrial hygienist in ensuring compliance with hazard communication legislation is obvious from initial risk assessment through employee training and MSDS interpretation.

ENFORCEMENT OF THE OSHAct

The secretary of labor is the principal administering officer of the OSHAct. OSHA is authorized to conduct inspections and, when alleged violations of safety and health standards are found, to issue citations and, when necessary, to assess penalties.

Highlights

- ➢ OSHA schedules inspections on a priority system: First, in response to fatalities and multiple (three or more) hospitalization incidents and imminent danger situations; second, in response to employee complaints; third, random inspections of high hazard industries; fourth, follow-up inspections.
- ➢ OSHA compliance officers may enter the employer's premises without delay to conduct inspections and usually without advance notice (section 8[a]); however, if the employer refuses entry, a search warrant may be requested.
- ➢ OSHA's right to inspect includes records of injuries and illnesses, including certain medical records.
- ➢ OSHA compliance officers who find conditions of imminent danger can only request, not demand, shutdown of an operation. If shutdown is refused, the compliance officer notifies employees of the hazard and the Department of Labor may seek court authority to shut down the operation.
- ➢ Criminal penalties can be invoked only by court action and in extreme cases (usually willful violations leading to death).
- ➢ An appeal system has been set up under which employers and employees can appeal certain OSHA actions to the independent Occupational Safety and Health Review Commission (OSHRC) (Section 12).

OSHA FIELD OPERATIONS

Field Inspection Reference Manual (FIRM)

The *Field Inspection Reference Manual* (*FIRM*) was issued in September 1994 by OSHA as a major revision to what was previously referred to as the *Field Operations Manual* (FOM). This manual contains general instructions and policies on field compliance operations. The OSHA *Technical Manual* sets forth the technical industrial hygiene practices and procedures used by OSHA personnel. This section summarizes these procedures and gives background about OSHA functions at the regional and local levels. Industrial hygienists within OSHA also receive substantial direction and information from the OSHA website, http://www.osha.gov.

Health compliance operations involve several technical and professional disciplines possessed by industrial hygienists, safety engineers, and safety specialists. Therefore, the processing of all health inspections and citations requires close coordination between industrial hygienists, engineers, and local, regional, and national staff. In addition, nonagency assistance, either from outside consultants or from other agencies such as NIOSH, may be required. (NIOSH is discussed later in this chapter.)

RESPONSIBILITIES

The national OSHA office, through its technical and analytical units, coordinates the technical aspects of health programming among the regions. An industrial hygienist in each regional office is responsible for coordinating the technical aspects of the health program within the region. This responsibility includes, but is not limited to, providing guidelines for inspections, evaluating and assisting in contested cases, and guidance in using technical equipment in accordance with criteria provided by the national office.

The Area Director. This official administers the field compliance program in the designated geographic area. Each area director designates an industrial hygiene supervisor, who is responsible for the technical aspects of the health compliance program and for recommending health inspection priorities in his or her area.

In state plan states, area directors and staffs are involved in monitoring the activities of the state staffs using performance measures for significant state plan activities. Simultaneously, the staffs in those offices enforce federal standards in workplaces not covered by the state plan, such as the maritime industry and military bases. *All* workers are covered in state plan states, including public sector, state, and local employees not covered in federal jurisdiction states.

Health inspections are conducted in industries in accordance with priorities outlined earlier. A health inspection can be either a complete survey of a particular workplace for all health hazards, or a special survey such as an accident investigation. Some inspections require a team effort because they involve more than one specialty. In such cases, the area director designates a team leader to coordinate the efforts.

COMPLIANCE OFFICERS

The officers doing inspections are provided cross-training in either safety or health, depending on their job classification, so that they are better able to recognize potential safety or health hazards.

Safety officers trained to recognize and evaluate health hazards are expected to collect information for possible referral to an industrial hygienist. Health referrals are incorporated into the regular inspection schedule.

Health complaints are investigated by an industrial hygiene compliance officer trained to recognize health hazards and evaluate conditions. Complaints involving the appropriateness of unusual medical testing or questionable results of medical findings are discussed with the regional industrial hygienist and the technical and analytical assistance unit.

OSHA's Reorganization and Reinvention

OSHA continues its reinvention effort, begun in 1995, in order to cope with the external factors that prevent the agency from continuing to perform in the traditional enforcement manner. Decreased resources, constant growth and transformation of the U.S. work force, and feedback from affected clients (management and employee "stakeholders") all contribute to that conclusion and the need to "reinvent." The OSHA offices have had to reorganize in terms of structure as well as methods. Rediscovered traditional tools as well as newly developed tools and methods have become the new means to the one and only goal, reduction in injuries, illnesses, and deaths.

The term used to identify the effort to examine existing processes in order to identify more efficient methods is Getting Results and Improving Performance (GRIP). Reinvented offices have eliminated duplicative procedures, reduced response times, and developed local initiatives, among other accomplishments. The GRIP model relies heavily on the team concept to proactively address challenges by focusing on getting results and improving office performance. In developing the right mix of proactive and reactive solutions, OSHA offices continue with strong enforcement upon recalcitrant employers and offer partnerships, outreach, and consultation to enlightened, cooperative employers.

A fundamental aspect of the GRIP model is the idea that all OSHA staff are responsible for accomplishing OSHA's mission of reducing workplace injuries, illnesses, and fatalities, not simply enforcing OSHA regulations. GRIP also focuses on achieving the following objectives:

- ➢ reducing injuries, illnesses, deaths
- ➢ increasing assistance provided to employers and employees in providing safe and healthful workplaces
- ➢ addresssing problems before they may result in workplace incidents
- ➢ concentrating limited resources on the worst hazards and workplaces
- ➢ delivering better public service in a more prompt and efficient manner
- ➢ creating a better place for OSHA field staff to work by building joint labor-management consensus

OSHA is confident that the GRIP approach will enable the agency to deliver on its 5-year Strategic Plan, the consequence of the Government Performance and Results Act of 1993. All government agencies developed such Plans in an effort to measure performance against desired results. The level of coordination and integration required throughout OSHA by the Plan is unprecedented in OSHA's history.

OSHA INDUSTRIAL HYGIENE INSPECTIONS

An industrial hygiene inspection is conducted by an industrial hygienist and often is complex and time-consuming.

The essential elements of a visit are preinspection planning, opening conference, walk-through inspection, sample collection, and closing conference. These guidelines are given to all OSHA industrial hygienists.

Preinspection Planning

The OSHA industrial hygienist should become familiar with the particular industry and general process information and size of the facility. The industrial hygienist should also review appropriate standards and select sampling methods. If the inspection is a referral visit to a workplace previously visited by a compliance officer, the industrial hygienist should review all information contained in the previous inspection reports. Based on both experience and specific study, he or she should select the necessary field instrumentation. The hygienist can then prepare instruments and equipment according to standard methods of sampling and calibration.

Opening Conference

The instructions state that on entering the establishment, the OSHA industrial hygienist presents identification credentials. An opening conference with facility management is arranged to discuss the purpose and scope of the inspection. If the employees are represented by a labor union, they must be notified of OSHA's presence and invited to participate in the inspection. At the beginning of inspection, the industrial hygienist usually requests a complete process flow diagram or facility layout or, if no layout chart is available, he or she can ask that a sketch be made to identify the operations, distribution of equipment including engineering controls, and approximate layout of the facility.

A brief examination is made of all required records kept at the establishment, such as the nature of any injuries or illnesses shown on OSHA form no. 200, Recordkeeping Log. Record-keeping requirements can be discussed at the closing conference after the inspection has been made or after sampling results have been analyzed. At this time, preliminary information is gathered about the occupational health program.

Walk-Through Inspection

A walk-through inspection is required for all health inspections regardless of whether the establishment was previously inspected. The main purpose of the walk-through inspection is to identify potential workplace health hazards; during the walk-through, the industrial hygienist becomes familiar with work processes, collects information on chemical and physical agents, and observes workers' activities. The industrial hygienist obtains information concerning raw materials used, intermediates (if any), and final products. Estimated amounts of substances present in the facility and a complete inventory are also obtained. In addition, the hygienist requests a list of raw materials received at the loading dock. He or she also checks for hazardous physical agents present in the facility, such as noise and excessive heat. He or she observes work activity throughout the facility, but concentrates particularly on potential health hazard areas.

The approximate number of workers in each area is written on the sketch of the facility. The industrial hygienist observes and records the general mobility of the workers and indicates whether they are engaged in stationary or transient activities. Existing engineering controls are marked on the facility layout or sketch. Ventilation measurements are made at strategic locations in the duct system and recorded on the facility sketch.

Information usually is requested from the facility manager concerning a preventive maintenance program for engineering controls. The industrial hygienist keeps alert for any imminent dangers during the walk-through inspections and takes appropriate action if necessary. Photographs can be taken to document the survey. Employee interviews are encouraged at this phase of the inspection.

In a small facility, health hazards sampling can be initiated after the opening conference. A final sampling schedule can be prepared using the information collected.

Collecting Samples

Representative jobs should be selected and personal sampling devices prepared. Operations with the highest expected exposure should be monitored first. The sampling program should be planned to follow industrial processes as closely as possible in order to keep information obtained in a logical sequence.

The OSHA industrial hygienist determines compliance with air quality and noise standards based on one or more days of full-shift, TWA concentration measurements. These findings are tempered by the hygienist's professional judgment of the data and conditions at the facility.

The TWA concentration must be determined for eight-hour exposures. Sampling devices monitoring full-shift exposures must operate for a minimum of seven hours. This implies that the concentration is calculated using the air volume sampled during the shift for a time greater than seven hours for some chemicals. Spot samples must be taken throughout the work shift to represent at least seven hours of exposure and to represent periods of exposure for TWA calculations. When the actual work shift exceeds eight hours, the TWA can be calculated using the results of seven- or eight-hour sampling periods and separate samples taken to determine any additional exposure. This value is compared with the standard for compliance determination.

Materials in Table Z–1 of OSHA Standard 1910.1000 preceded by a *C* have maximum peak ceiling limits to which an employee can be exposed; these values are never to be exceeded. Generally, a 15-minute sampling period should be applied to ceiling measurements (except for imminent danger situations where immediate escape from the atmosphere is necessary).

A minimum number of samples must be taken. These can be a single eight-hour sample for full-shift assessment, several spot samples that represent on a TWA a full-shift assessment, or one 15-minute sample for a ceiling assessment. The measurements must exceed the sum of the allowable limit and a calculated margin of error before a citation can be issued.

The criteria for determining full-shift TWA concentrations have been developed because legal considerations require a degree of certainty that the standard has been violated when a citation is issued. A citation shall not be issued unless the measured level exceeds the calculated upper confidence level of the permissible level based on a single day's sampling results. Measurements below the confidence limit indicate that overexposure may have occurred.

All sampling equipment must be checked and calibrated (in accordance with standard procedures described in the *OSHA Technical Manual*) before sampling. The sampling for both physical and chemical contaminants in the environment must relate to the worker's exposure, unless otherwise specified in a standard. In order that measurements represent, as far as possible, actual exposure of the employee, the measurements for air pollutants should be taken from the employee's breathing zone; measurements for noise exposures should be taken near the ear.

Closing Conference

Because the industrial hygienist may not have the results of the environmental measurements at the end of the inspection or during the closing conference, a second closing conference may be held; for this, a telephone call or a letter can be used in place of a personal visit. Employees or their representatives are also informed of the inspection results at that time. If the results indicate noncompliance, the alleged violations can be discussed at the second conference, along with abatement procedures and methods of control.

Employer's Occupational Health Programs

Information on the following aspects of the employer's occupational health program is gathered during the inspection for evaluation. These aspects may be discussed during the closing conference and later considered in relation to the standard requirements and also as evidence of good faith when penalties are being proposed.

MONITORING PROGRAM

Detailed information concerning the industrial hygiene program is obtained. Especially valuable data that are asked for include number and qualifications of personnel and availability of necessary sampling and calibration equipment, ventilation-measuring equipment, and laboratory services.

MEDICAL PROGRAM

The industrial hygienist should determine whether the employer provides employees with preemployment and regular medical examinations as required by certain OSHA standards. The medical examination protocol is reviewed to determine the extent of the medical examination.

EDUCATION AND TRAINING PROGRAMS

A special check is made to evaluate the company's efforts to comply with the Hazard Communication Standard 1910.1200, the Hazwoper Standard 1910.120, Personal Protective Equipment 1910.132, 1910.134, and 1910.139, Subpart Z—Toxic and Hazardous Chemicals in Laboratories, and other standards.

RECORD-KEEPING PROGRAM

The employer's record-keeping program is checked, including types of records, how long they are maintained, and the accessibility of these records to employees.

Compliance Programs

The industrial hygienist determines the employer's implementation of engineering and administrative controls and checks appropriate equipment and preventive maintenance. A specific engineering control should be evaluated for effectiveness in its present application.

WORK-PRACTICE AND ADMINISTRATIVE CONTROLS

Control techniques include the redesign or modification of equipment, isolation of hazardous operations, rotation of employee job assignments, use of personal protective equipment, and sanitation and housekeeping practices. A detailed description of such controls should be obtained. It is essential that work practice controls and the education program be implemented simultaneously because the overall effectiveness of such practices is enhanced by employees' knowledge of their exposures.

PROTECTIVE DEVICES

The industrial hygienist determines whether protective devices are effectively used in the facility. A detailed investigation of the personal protection program includes a determination of compliance with 29 *CFR* 1910.132, 134, and 139, which include the General Requirements as well as Respiratory Protection Standards.

REGULATED AREAS

Some standards require the establishment of regulated areas, where concentrations exceed the PELs. Sampling is used to determine the limits of areas that must be regulated because employee exposure is expected to be greater than prescribed levels. The industrial hygienist makes sure that regulated areas meet the following standards:

- ➢ They must be clearly identified and known to affected employees.
- ➢ Regulated areas shall be demarcated and segregated from the rest of the workplace in a manner that minimizes the number of people who will be exposed to a chemical. The regulated area designations must be maintained according to the criteria of the standard.
- ➢ Daily rosters of authorized personnel entering and leaving the area must be maintained. Summaries of such rosters are acceptable.

EMERGENCY PROCEDURES

Some standards provide for specific emergency procedures to be followed when handling certain hazardous substances.

Company procedures should be checked for the inclusion of potential emergency conditions in the written plan, explanation of such emergency conditions to the employees, training schemes for the protection of affected employees, and delegation of authority for the implementation of the operational plan in emergency situations.

EVALUATION OF SAMPLING DATA

OSHA industrial hygienists use professional judgment when evaluating the data and conditions to confirm the sampling results. Sampling results should reasonably correlate with each other. For example, an occupation that is expected to be dusty should have higher dust concentrations measured than those expected to be less dusty. Sampling results must reasonably correlate with previous measurements made by OSHA, the company, and others (taking into account variations due to weather, production, breakdowns, and the like). The sampling results must take into account accuracy of the instrument. The industrial hygienist's record must state that all sampling was performed according to OSHA standard methods.

Issuance of Citations

The industrial hygienist uses OSHA guidelines when classifying violations. Here are some examples.

- ➢ The workplace may be found to be in compliance with OSHA standards. In this case, no citations are issued or penalties proposed.
- ➢ Violations may be found in the establishment. In that case, citations may be issued and civil penalties may be proposed. In order of significance, these are the types of violations or conditions normally considered on a first inspection.

IMMINENT DANGER

An *imminent danger* is a condition where there is reasonable certainty a hazard exists that can be expected to cause death or serious physical harm immediately or before the hazard can be eliminated through regular procedures. If the employer fails to abate such conditions immediately, the compliance officer, through his or her area director, can go directly to the nearest federal district court for legal action as necessary.

SERIOUS VIOLATIONS

A *serious violation* has a substantial probability that death or serious physical harm could result and that the employer knew, or should have known, of the hazard. An example is the absence of point-of-operation guards on punch presses or saws. A serious penalty may be adjusted downward based on the employer's good faith, history of previous violations, and size of the business.

WILLFUL VIOLATIONS

A *willful violation* exists where the evidence shows either an intentional violation of the act or indifference to its requirements.

The employer commits an intentional and knowing violation under either of the following conditions:

- ➢ An employer representative is aware of the requirements of the act or the existence of an applicable standard or regulation and is also aware of a condition or practice in violation of those requirements.
- ➢ An employer representative is not aware of the requirements of the act or standards but is aware of a comparable legal requirement (such as state or local law) and is also aware of conditions in violation of that requirement.

The employer commits a violation with *plain indifference* to the law under any of the following conditions:

- ➢ Higher management officials are aware of an OSHA requirement applicable to the company's business but make little or no effort to communicate the requirement to supervisors and employees.
- ➢ Company officials are aware of continuing compliance problems but make little or no effort to avoid violations (an example is repeated issuance of citations addressing the same or similar conditions).
- ➢ An employer representative is not aware of any legal requirement but is aware that a condition or practice is hazardous to the safety or health of employees and makes little or no effort to determine the extent of the problem or to take the corrective action. Knowledge of a hazard may be gained from insurance company reports, safety committee or other internal reports, the occurrence of illnesses or injuries, media coverage, or, in some cases, complaints of employees or their representatives.
- ➢ In particularly flagrant situations, willfulness can be found despite lack of knowledge of a legal requirement or a hazard if the circumstances show that the employer would not place importance on such knowledge even if he or she possessed it.

It is not necessary that the violation be committed with a bad purpose or an evil intent to be deemed willful. It is sufficient that the violation was deliberate, voluntary, or intentional as distinguished from inadvertent, accidental, or ordinarily negligent.

The determination of whether to issue a citation for a willful or repeated violation often raises difficult issues of law and policy and requires the evaluation of complex factual situations.

CRIMINAL/WILLFUL VIOLATIONS

An employer who willfully violates any standard, rule, or order, if that violation caused death to any employee, will, on conviction, be punished by a fine or by imprisonment for not more that six months, or both. If the conviction is for a violation committed after a first conviction, the punishment will be a fine or imprisonment for not more than one year, or both.

In order to establish a *criminal/willful violation* OSHA must prove that the employer violated an OSHA standard. A criminal/willful violation cannot be based on violation of

section 5(a)(1). OSHA must also prove that the violation was willful in nature. See discussion of *willful* above.

REPEATED VIOLATIONS

An employer may be cited for a *repeated violation* if that employer has been cited previously for a substantially similar condition and the citation has become a final order. Generally, similar conditions can be demonstrated by showing that in both situations the identical standard was violated. In some circumstances, similar conditions can be demonstrated when different standards are violated.

REPEATED VERSUS WILLFUL

Repeated violations differ from willful violations in that they may result from an inadvertent, accidental, or ordinarily negligent act. If a repeated violation also meets the criteria for willfulness, but not clearly so, a citation for a repeated violation is normally issued.

REPEATED VERSUS FAILURE TO ABATE

A *failure to abate situation* exists when an item of equipment or condition previously cited has never been brought into compliance and is noted at a later inspection. However, if the violation was not continuous (i.e., if it had been corrected and then recurred), the subsequent occurrence is a repeated violation.

EGREGIOUS CITATIONS

Cases under consideration for treatment as *egregious* must be classified as willful (as described above) and meet one of the following criteria:

- ➢ The violations resulted in a worker fatality, a worksite catastrophe, or a large number of injuries or illnesses.
- ➢ The violations resulted in persistently high rates of worker injuries of illnesses.
- ➢ The employer has an extensive history of prior violations of the act.
- ➢ The employer has intentionally disregarded its safety and health responsibilities.
- ➢ The employer's conduct taken as a whole amounts to clear bad faith in the performance of his or her duties under the act.
- ➢ The employer has committed a large number of violations so as to undermine significantly the effectiveness of any safety and health program in place.

OTHER-THAN-SERIOUS VIOLATIONS

Other-than-serious violations are those that have a direct relationship to job safety and health but probably would not cause death or serious physical harm, such as a tripping hazard. A nonserious penalty may be adjusted downward depending on the severity of the hazard, employer's good faith, his or her history of previous violations, and the size of the business. Congress has told OSHA that, exclusive of serious violations, it must find more than 10 other violations before any penalty can be imposed.

DE MINIMIS

A *de minimis violation* is a condition that has no direct or immediate relationship to job safety and health.

If respirators and other personal protective equipment are not properly fitted or are not worn and the affected employee is exposed to a toxic agent above the PEL, a citation will be issued, classified as serious.

Employers may be cited for an other-than-serious violation if, for example, they have not established written operating procedures governing the use of respirators, have not trained and instructed employees in their proper use, or have not regularly cleaned and disinfected the respirators even though such respirators are properly fitted and worn.

Sometimes, when appropriate personal protective equipment is being used properly, citations are issued for failure to use administrative or engineering controls if the industrial hygienist believes that such controls are feasible. Generally, such citations will be other-than-serious unless available data indicate that the personal protective equipment, although properly fitted and worn, is not effective in fully reducing exposure to acceptable limits as required by the standard.

OSHA has technical support units and compliance organizational units in its regional and national offices, with staffs that provide guidance to the field compliance officers. The goal is to establish and maintain uniform compliance activities across the nation so that hazardous conditions are not cited differently by different inspectors. These support groups help determine which engineering controls are feasible and give this information to OSHA industrial hygienists to help them judge whether an item is serious or nonserious.

During an inspection, the industrial hygienist carefully investigates the source or cause of observed hazards to determine whether some type of engineering or administrative control (or combination) may be applied that would significantly reduce employee exposure. In order to issue a citation, an OSHA representative need not show that the controls would reduce exposure to the limits prescribed by the applicable standard.

Engineering Controls

Engineering controls include any procedure, other than administrative controls or use of personal protective equipment, that reduces exposure at its source or close to the employee's breathing or hearing zone. Proper work practices and personal hygiene facilities are defined as engineering controls. For a particular engineering control to be feasible, a general technical knowledge about the materials or methods available or adaptable to the specific conditions must exist. There must be a reasonable possibility that these materials and methods will reduce employee exposure to violative conditions of noise, dust, or other substances.

Contest of OSHA Citations

If an employer disagrees with a citation or proposed penalty, he or she can request an informal meeting with the area director to discuss the case.

If the employer decides to *contest the citation*, the act contains a specific appeal procedure, guaranteeing full review of the case by an agency separate from the Department of Labor. That agency is the independent Occupational Safety and Health Review Commission (OSHRC), which has no connection with the U.S. Department of Labor.

The OSHRC was created to adjudicate enforcement actions initiated under the act when they are contested by employers, employees, or representatives of employees.

The commission's functions are strictly adjudicatory; however, it is more of a court system than a simple tribunal, for within the OSHRC there are two levels of adjudication. All cases that require a hearing are assigned to an OSHRC judge, who decides the case. Each such decision is subject to discretionary review by the three members of the OSHRC on the motion of any one of the three.

Employers may contest a citation, a proposed penalty, a notice of failure to correct a violation, the time allotted for abatement of a violation, or any combination of these. Employees or employee representatives can contest the time allotted for abatement.

A notice of contest must be filed by certified mail. The OSHA area office initiates the action being contested within 15 federal working days of receipt of the notice of the enforcement action, so if the notice of contest is not filed within 15 working days, the proposed penalties and citations are final and not subject to review by any court or agency.

There is no prescribed form for the notice of contest. However, the notice must clearly indicate what is being contested, whether it is the citation, the proposed penalty, or the time for abatement.

Employees working on the site of the alleged violation must be notified of a contest filed by their employer. If they are members of a union, the union must be given a copy of the notice of contest. The employer must notify nonunion employees either by posting a copy of the notice of contest where they will see it or by serving each a copy.

The notice of contest must contain the names of those to whom it has been served or the address of the place it was posted. The posted or individually served copy of the notice of contest must be accompanied by a warning that the employees or employee representatives may not be allowed to participate in the case unless they identify themselves before the hearings begin to the commission or hearing examiner. This is called filing for party status. To file for party status, an employee or employee representative must send a notice of intent to the OSHRC. If an employer contests an alleged violation in good faith and not solely for delay or variance of penalties, the abatement period does not begin until the entry of the final order by the OSHRC.

When a notice of contest reaches the area director, the executive secretary of the OSHRC is notified of the contest and its details. The latter gives the case a docket number.

In time, a hearing will be held by an OSHRC judge. OSHA first presents its case, subject to cross-examination by the other parties. The defendant then presents the case, subject to cross-examination by the other parties. Employees or their representatives may participate in this hearing if they have filed for party status. The judge is allowed to consider only what is on the record. Any statements that go unchallenged are therefore considered to be fact.

The hearing is ordinarily held in or near the community where the alleged violation occurred. At the hearing, the secretary of labor has the burden of proving the case.

After the hearing, the judge must issue a report based on findings of fact that affirms, modifies, or vacates the secretary's citation or proposed penalty or that directs other appropriate relief. The report becomes a final order of the commission 30 days thereafter unless, within such period, a commission member directs that such report shall be reviewed by the commission itself. When this occurs, the members of the commission issue their own decisions on the case.

Once a case is decided, any person adversely affected or aggrieved thereby may obtain a review of such decision in the United States Court of Appeals.

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

The National Institute for Occupational Safety and Health (NIOSH) is the principal federal agency engaged in research to eliminate on-the-job hazards to the health and safety of American workers. It was established within the Department of Health, Education, and Welfare (now the DHHS) under the provision of Public Law 91–596, the Occupational Safety and Health Act of 1970. Administratively, NIOSH is located within DHHS's Centers for Disease Control of the Public Health Service.

Responsibilities

NIOSH is responsible for identifying occupational safety and health hazards and for recommending changes in the regulations limiting them. It also is responsible for training occupational health personnel.

The institute's main research laboratories are in Cincinnati, Ohio, where studies include not only the effects of exposure to hazardous substances used in the workplace, but also the psychological, motivational, and behavioral factors involved in occupational safety and health. Much of the institute's research centers on specific hazards, such as asbestos and other fibers, beryllium, coal tar pitch volatiles, silica, noise, and stress.

At the NIOSH Appalachian Laboratory for Occupational Safety and Health (ALOSH) in Morgantown, West Virginia, research has primarily focused on coal workers' pneumoconiosis (black lung disease), but the program has been expanded to include other occupational respiratory diseases. Also located in Morgantown is the NIOSH Testing and Certification Branch, which evaluates and certifies the performance of respirators.

Testing and Certification

Certification tests are performed under the authority of the Federal Coal Mine Health and Safety Act of 1969, the Occupational Safety and Health Act of 1970, and the numerous regulations and standards issued by the Mine Safety and Health Administration (MSHA) and the Occupational Safety and Health Administration (OSHA).

These tests have three purposes. First, they determine whether currently available protective devices conform or fail to conform with existing performance standards for such devices. Second, they encourage manufacturers of such devices and instruments to improve their performance and quality when NIOSH finds them to be out of conformance or of marginal quality. Third, the results of the tests are used by NIOSH in determining the need for future NIOSH certification projects and in establishing priorities for research directed at product improvements through increased quality and scope of performance testing.

The NIOSH personnel, in addition to doing respirator research, serve as consultants to OSHA and industry on respirator selection, use, and maintenance. NIOSH personnel regularly participate in OSHA hearings and submit new respirator information to OSHA and industry on a routine basis.

Research

In addition to conducting its own research, NIOSH funds supportive research activities at a number of colleges, universities, and private facilities.

Not all of NIOSH's work is done in the laboratories. A legislatively mandated activity involves Health Hazard Evaluations (HHEs); these are on-the-job investigations of reported worker exposures to toxic or potentially toxic substances. Performed as a direct response to requests by management or authorized representatives of employees, HHEs are usually initiated through NIOSH's representatives, although scientists from other institute facilities often are involved.

Under the authority of the OSHAct, NIOSH conducts research for new occupational safety and health standards. Its recommended standards are transmitted to the Department of Labor, which has the responsibility for development, promulgation, and enforcement of the standards.

Training

NIOSH has training grant programs in colleges and universities across the nation. These are located at designated NIOSH-funded Educational Resource Centers (ERCs) for the purpose of training occupational physicians and nurses, industrial hygienists, engineers, and others in the safety and health field. Typical ERCs establish cooperative arrangements with medical schools and hospitals with established programs in occupational medicine and incorporate and expand on such existing programs.

NIOSH also maintains a limited number of Regional Offices throughout the United States. The Regional Offices are focal points for special surveys and evaluations of existing occupational safety and health problems, consultative services to the states, and other activities. NIOSH headquarters are in Atlanta.

Recommendations for Standards

One of NIOSH's most important responsibilities under this act is to transmit recommended standards to OSHA. NIOSH recommendations are intended to assist OSHA in developing new standards and in revising the approximately 400 consensus health standards (most of them consist only of a numerical exposure limit) that were promulgated when the act was passed.

NIOSH recommendations, called Criteria Documents, include an environmental limit for workplace exposure as well as recommendations on the use of labels and other forms of warning, the type and frequency of medical examinations to be provided by the employer, sampling and analytical methods, procedures for technological controls of hazards, and suitable personal protective equipment. In addition to the criteria documents, NIOSH developed technical standards for most of the consensus health standards. These standards supplement the existing environmental limits with procedures for informing employees of hazards, monitoring techniques, engineering and control mechanisms, and medical surveillance programs. These recommendations should protect workers from many of the more serious occupational exposures. These recommendations are based on laboratory and epidemiologic research conducted by NIOSH and other organizations.

Field Investigations

NIOSH has promulgated regulations governing field investigations (42 *CFR* Part 85). Under these regulations, it is the practice to meet with company management and employee representatives before initiating a study in order to explain its purpose and scope. Before conducting medical examinations, investigators must receive specific approval from the NIOSH Human Subjects Review Board and obtain the informed consent of each employee examined. All participating employees and their designated physicians are given the results of these medical examinations. Before final reports on group data (with individual identifiers removed) are released, draft copies are provided to employers and employee representatives for their comments on technical accuracy. The results of the epidemiologic studies are then presented in NIOSH criteria documents and technical reports, in scientific journals, at scientific meetings, and at OSHA hearings on workplace standards.

Workplace investigations also are conducted in a health hazard evaluation program. Under this program, NIOSH responds to requests from employers and employee representatives to investigate a workplace, collect environmental samples, make toxicity determinations, and provide medical examinations for workers. The results of these investigations,

including recommendations for work practices, personal protective equipment, and engineering controls, are reported back to company or facility management, employee representatives, and OSHA.

OTHER U.S. GOVERNMENT REGULATORY AGENCIES

In addition to OSHA and NIOSH, there are other federal government regulatory agencies and commissions.

Mining Enforcement and Safety Administration

The Mining Enforcement and Safety Administration (MESA) was established on May 7, 1973, by the secretary of the interior; the administration became operative on July 16, 1973. The secretary's order assigned to MESA the responsibility for administering the enforcement provisions of the Federal Coal Mine Health and Safety Act of 1969 and the Federal Metal and Nonmetallic Mine Safety Act.

MESA administered the enforcement provisions of the public laws and related standards and training programs in a manner that guards the health and safety of American miners.

The secretary's order of May 7, 1973, designated the Bureau of Mines of the Department of the Interior to continue its research functions for mine health and safety.

Federal Mine Safety and Health Amendments Act of 1977

On November 9, 1977, President Carter signed the Federal Mine Safety and Health Amendments Act of 1977. The act transfers authority for enforcement of mining safety and health from the Department of Interior to the Department of Labor. Most of the provisions of the act became effective March 9, 1978.

The Federal Mine Safety and Health Act of 1977 repeals the Metal and Nonmetallic Mine Safety Act and establishes a single mine safety and health law for all mining operations under an amended Coal Mine Health and Safety Act of 1969.

The Mine Safety and Health Administration (MSHA) was created to replace the Department of the Interior's Mining Enforcement and Safety Administration. This agency is headed by the assistant secretary of labor for mine safety and health. The new agency is separate from OSHA and the secretary of labor and is authorized to settle jurisdictional disputes between the two agencies.

The 1977 act defines *mine* broadly to include all underground or surface areas from which a mineral is extracted, all surface facilities used in preparing or processing minerals, and all roads, structures, dams, impoundments, tailing ponds, and similar facilities related to mining activity. Included under the act is the protection of miners from radiation hazards connected with the milling of certain radioactive materials. Mine construction activity on the surface is included in the scope of the act.

The act does not amend the section of the Coal Act dealing with benefits for victims of black lung disease.

PROVISIONS

The Federal Mine Safety and Health Act of 1977 joins all mines (coal and noncoal) under one statute, transfers administration from the Department of the Interior to the Department of Labor, provides that existing and new standards applicable to metal and nonmetal mining remain separate from existing and new standards for coal mining, and establishes statutory timetables for each step of the standard-setting process.

This act vests in the secretary of labor all authority for developing safety and health standards; it authorizes NIOSH to prepare criteria documents for the development of health standards, with the secretary of labor required to act within 60 days of receipt of criteria.

FEDERAL MINE SAFETY AND HEALTH REVIEW COMMISSION

This act established an independent Federal Mine Safety and Health Review Commission. It requires each mine operator to have a safety and health training program that is approved by the secretary of labor (with such training to be provided at the operator's expense and during normal working hours) and authorizes miners' representatives to participate in inspections not only during the actual inspection, but also in pre- and post-inspection conferences held at the mine. More than one miner representative may participate, but only one representative, who is also an employee of the operator, is to be paid by the operator for participation in the inspection and conferences.

The act authorizes a withdrawal order (an order to stop operations) based on a pattern of standards violations that could "significantly or substantially contribute to the cause and effect of a mine hazard and health risk," authorizes miners or their representatives to make written requests for inspection based on suspected violations of standards or conditions of imminent danger, and mandates a minimum of two inspections per year of all surface mines.

The secretary of DHHS is required to appoint an advisory committee on mine health research composed of representatives of the director of the Bureau of Mines, the director of the National Science Foundation, and the director of the National Institutes of Health (NIH), as well as other people knowledgeable in the field of mine health research. The secretary of DHHS also designates the committee chairman.

The purpose of the advisory committee is to consult with and make recommendations to the secretary of DHHS on matters relating to mine health research. The secretary is required to consider the recommendations of the committee in the conduct of such research and the awarding of research grants and contracts. The chair and the majority of committee members are not permitted to have economic interests in mining or be miners, mine operators, or government

employees. In effect, the new mining law expands the existing Coal Mine Health Research Advisory Committee to cover all mine health research.

Under the existing Federal Coal Mine Health and Safety Act of 1969, NIOSH conducted research on occupational diseases of coal miners, established coal mine health standards, and ensured the availability of medical examinations for underground coal miners. MESA established coal mine safety standards and enforced both health and safety standards. In addition, NIOSH has established joint regulations with MESA to test and certify respirators and coal mine dust personal samplers.

In the past, NIOSH has not had specific legislative authority to conduct research in noncoal mines but has done so under the general authority of the Public Health Service Act and as designees of the Department of the Interior. Under the OSHAct, NIOSH has developed recommended standards that could apply to some of the most important health hazards facing workers in metal and nonmetal mines, such as noise, silica, asbestos, beryllium, and arsenic.

The new legislation changed NIOSH research authority into occupational diseases of coal miners significantly. The law does provide specific authority to conduct health hazard evaluations and establish a list of toxic substances and hazardous physical agents found in mines. Significantly, however, instead of actually setting coal mine health standards, as provided by the Coal Act, NIOSH would submit recommended standards to the Department of Labor, as is done under the OSHAct.

Research on health hazards in metal and nonmetallic mines has been expanded considerably because NIOSH had not previously had specific authority to investigate conditions in such workplaces and develop standards.

Environmental Protection Agency

TOXIC SUBSTANCES CONTROL ACT

In 1976, Congress enacted the Toxic Substances Control Act (TSCA), PL 94–469. The act provides the Environmental Protection Agency (EPA) with the authority to require testing of chemical substances entering the environment and to regulate them when necessary. The regulatory actions include toxicity testing and environmental monitoring. This authority supplements and closes the loop of already existing hazardous substance laws in the EPA and other federal agencies. Title I of TSCA also included a provision requiring the EPA to take specific steps to control the risk for polychlorinated biphenyls (PCBs). Three titles have been added to TSCA to address concerns about other specific toxic substances, including asbestos (Title II), radon (Title III), and lead (Title IV).

Title II of TSCA, the Asbestos Hazard Emergency Response Act (PL 99–519), was enacted in 1986 and amended in July 1988. It required the EPA to set standards for responding to the presence of asbestos in schools. The standard set responses based on the physical condition of asbestos and schools were required to inspect for asbestos-containing material and develop a management plan for such material. The title also requires asbestos contractors and analytical laboratories to be certified and requires schools to use certified people for asbestos work. The title was later amended to extend training and accreditation requirements to include inspectors, contractors, and workers performing asbestos abatement work in all public and commercial buildings. However, the mandate for inspecting buildings for asbestos was not extended to nonschool buildings.

In 1988, Title III, Indoor Radon Abatement (PL 100–551), was added to TSCA. The basic purpose of the amendment is to provide financial and technical assistance to states that support radon monitoring and control; however, neither monitoring nor abatement is required by the act. The title required the EPA to update its pamphlet on radon, develop model constructions standards and techniques for controlling radon levels in new buildings, and provide technical assistance to the states.

Title IV of TSCA, the Residential Lead-Based Paint Hazard Reduction Act (PS 102–550), was enacted in 1992. The purpose of this title is to reduce the risks to young children who are exposed to lead-based paint in their homes. The law aims to stimulate development of lead inspection and hazard abatement services in the private sector. The EPA is directed to develop definitions of lead-contaminated dust, lead-contaminated soil, and lead-based paints hazards; requirements for accreditation of training programs for lead abatement work; criteria to evaluate the effectiveness of commercial products used to detect or reduce risks associated with lead-based paint; protocols for laboratory analysis of lead in paint soils, films, and dust; and certification requirements for laboratories performing such analyses. Also, the EPA is directed to conduct a study of lead hazards due to renovation and remodeling activities that may disturb lead-based paint. It must also promulgate guidelines for the renovation and remodeling of buildings or other structures when these activities might create a hazard.

RESOURCE CONSERVATION AND RECOVERY ACT

The Resource Conservation and Recovery Act (RCRA) of 1976 established the federal program regulating solid and hazardous waste management. RCRA actually amends earlier legislation (the Solid Waste Disposal Act of 1965), but the amendments were so comprehensive that the act is commonly called RCRA rather than its official title. The act greatly expanded the federal government's role in solid waste disposal management, with emphasis on hazardous waste disposal. RCRA continued the federal facilities guidelines under the program established by the 1970 Solid Waste Disposal Act, created a major hazardous waste regulatory program, and prohibited the practice of open dumping. The act provides for extensive federal aid through grants to state and regional agencies for solid waste planning and information programs.

In the cradle-to-grave program of control established by RCRA, custody and responsibility moves with a waste material from the generator and transporter to its final disposal site. However, the generator never loses liability for the waste created. Although the original RCRA regulations (1980–1984) exempted small-quantity generators if they produced less than 1,000 kg of hazardous waste per calendar month, the 1984 amendments to RCRA require generators producing between 100 and 1,000 kg per month to meet certain procedural standards.

Since 1980, general waste management requirements of RCRA have included proper notification and recording of hazardous waste activities, along with adequate packaging, labeling, and manifesting of wastes for shipment off site. A RCRA permit is required for treatment, storage, and disposal (TSD) of hazardous waste on-site or off-site. Standards for TSD facilities include rigorous facility management plans, preparedness and prevention of emergencies and releases, contingency plans, operating records and reports, groundwater protection for land disposal facilities, and closure and postclosure plans with financial responsibility assurance.

The new RCRA requirements, following the amendments of 1984, make TSD facilities responsible for assessing human exposure to current and past waste management operations and for corrective action needed to remedy releases of hazardous constituents to the environment. The RCRA regulations also require worker training, development of safe handling procedures, and emergency response measures. Documentation of training is required and inspectors may require a review of the documentation.

The 1984 amendments required that land disposal of specified highly hazardous wastes be phased out over the period 1986–1990. The EPA was directed to review all wastes that it has defined as hazardous and to determine the appropriateness of land disposal for them. Minimal technological standards were set for new landfills, generally requiring double liners, a leachate collection system, and groundwater monitoring. Under the new amendments, states were encouraged to assume the EPA's hazardous waste program. As of September 1992, 46 states were authorized to run the pre-1984 elements of the programs and 6 had received authorization to run most post-1984 components as well.

The third major amendment to RCRA, the Federal Facility Compliance Act, was passed in 1992. This act allows the states, the EPA, and the Department of Justice to enforce the provisions of RCRA against federal facilities; federal departments and agencies can be subjected to injunction, administrative orders, or penalties for noncompliance. The act also contains special provisions applicable to mixtures of radioactive and hazardous waste at Department of Energy facilities and to munitions, military ships, and military sewage treatment facilities handling hazardous wastes.

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT

In 1980, Congress enacted the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), PL 96-510. This act established the Superfund Program to handle emergencies at uncontrolled waste sites, to clean up the sites, and to deal with related problems. In 1986, CERCLA was reauthorized by Congress as the Superfund Amendment and Reauthorization Act (SARA) of 1986, PL 99-499. The purpose of the amendments was to provide additional funding and additional provisions. The new authorities and programs included in this reauthorization include underground storage tanks, emergency planning, risk assessment, community right-to-know, research, development, demonstrations, and training. In 1990, the Superfund Extension Act authorized appropriations for SARA through 1995.

These regulations include requirements that owner-operators of leaking underground storage tanks undertake corrective action to protect human health and the environment. SARA also established a comprehensive federal program to promote various research, development, demonstration, and training activities, including the following:

- Techniques to detect, assess, and evaluate health effects of hazardous substances
- Methods to assess human health risks
- Methods and technologies to detect hazardous substances and to reduce volume and toxicity

CERCLA created the Agency for Toxic Substances and Disease Registry (ATSDR) in the Public Health Service to carry out the health-related authorities in the act. In 1986, SARA created new duties for ATSDR. The agency and EPA are to prepare a list of at least 275 of the hazardous substances most commonly found at National Priority List (NPL) sites. The agency is to prepare toxicological profiles of these substances. Where there is insufficient information on a substance, ATSDR is to conduct research. In addition, ATSDR is required to perform a health assessment at each facility on the NPL list. Finally, ATSDR is to provide consultations to the EPA and state and local officials on health issues related to hazardous substances.

With the RCRA amendments and the requirements for cleanup under the CERCLA legislation, the time of total accountability for current and past waste management practices has arrived. Quantitative liabilities for waste management practices are directly proportionate to how much a facility is affected by these requirements and remedial actions. The 1986 law added a provision limiting the amount of coverage specified in the policy. SARA also authorized companies to form risk retention groups as a means of insuring themselves.

Companies covered under the OSHA Hazard Communication standard are also subject to the EPA Hazardous Chemical Reporting Rules under Title III of Superfund.

Covered facilities are required to submit either copies of the MSDSs they prepare for OSHA compliance or a list of all chemicals for which MSDSs are required to the state emergency response commission, the local emergency planning committee, and the local fire department.

Covered facilities must also submit emergency and hazardous chemical inventory forms to the same state and local authorities. Information on the maximum daily amounts and chemical locations (designated Tier I information) submittal date was March 1, 1988, and annually thereafter. The more detailed Tier II information would be submitted on request.

SUMMARY

This chapter provides an overview of the national, regional, and state government agencies and regulations concerned with occupational health, safety, and environmental issues. The history of the Occupational Safety and Health Administration and relevant legislation are detailed in Chapter 29.

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Chapter

29

History of the Federal Occupational Safety and Health Administration

by Benjamin W. Mintz, LLB

*Testifying before a congressional subcommittee in 1968, Secretary of Labor Willard Wirtz spoke dramatically of the industrial casualty rate. "Each day," he stated, "there will be 55 dead, 8,500 disabled and 27,200 hurt in America's workplaces." Secretary Wirtz was pressing the subcommittee to approve the comprehensive federal occupational safety and health bill, which was being sponsored by the administration of President Lyndon B. Johnson. The issue, Secretary Wirtz asserted, is "simply whether the Congress will act to stop a carnage which continues only because people don't realize its magnitude, and can't see the blood on the things they buy, on the food they eat, and the services they get." Dr. Irving Selikoff, a pioneer in the field of occupational medicine, testified that it was an "unhappy reflection" on the country that in the 1960s in the United States, 7 percent of all insulation workers would die of asbestosis, a "completely preventable disease" (*OSHAct: Hearings on S. 2864 Before the Subcomm. on Labor of the Senate Comm. on Labor and Public Welfare, *90th Cong., 2nd Sess. 69 [1968]).*

Despite this testimony, Congress did not pass occupational safety and health legislation that year. Not until 1970, after a difficult legislative battle, was an OSHA law enacted. It was signed into law by Richard Nixon on December 29, 1970, and became effective 120 days later.

Fifteen years later, in April 1985, a major report on OSHA entitled Preventing Illness and Injury in the Workplace *was issued by the Office of Technology Assessment (OTA) of the Congress. The OTA estimated that there were between 2.5 and 11.3 million nonfatal occupational injuries each year and 6,000 deaths annually resulting from workplace injuries. Noting the great disagreement about the number of workplace illnesses, OTA refused even to estimate the correct number (OTA, 1985).*

This chapter covers the history of OSHA from 1970 to 2001, in a framework that details OSHA's achievements and failures during its 31-year history.

1968–1970: THE AGENCY IS CREATED
The Legislative Battle

The 91st Congress is remembered as the occupational safety and health Congress. In 1969, it passed two landmark statutes: the Coal Mine Safety Act and the Construction Safety Act. In December 1970, the most comprehensive statute of all, the OSHAct, was adopted by overwhelming votes in the Senate and the House of Representatives (OSHAct, 29 U.S.C. §651 and following). Earlier in 1968, a federal OSHA bill was introduced but did not reach a vote, largely because of strong opposition from the business community. A representative of the American Iron and Steel Institute told a subcommittee that voluntary employer efforts, along with state activity and federally sponsored research, would accomplish far more in reducing workplace injuries "than would a program of federal penalties and other attributes of overwhelming federal authority reaching into hundreds of thousands of large and small business operations" (*OSHAct: Hearings on S. 2864 Before the Subcomm. on Labor of the Senate Comm. on Labor and Public Welfare,* 90th Cong., 2nd Sess. 347, 349-352 [1968]).

In 1969, with support from newly elected President Nixon, a broad consensus had emerged on the need for federal legislation to prevent illnesses and injuries in the workplace. Several important factors contributed to this consensus:

- In the past, the workers' compensation system had not provided sufficient financial incentives for employers to undertake efforts to improve workplace safety and health.
- The accident rate was rising.
- Illness in the workplace was a serious and rapidly increasing problem.
- State efforts had proven inadequate (MacLaury, 1981, p. 18).

The main issue was what the substance of the legislation would be. There was basic agreement on several points; for example, broad coverage by the new law, the need for occupational safety and health standards prescribing the employer conduct necessary to achieve safety and health, government enforcement of these standards, and a role for the states in the program. The disagreement centered on the extent of the powers to be assigned to the secretary of labor. The unions, generally supported by Democratic members of Congress, favored a strong role for the secretary of labor. They argued in favor of that office's authority to issue standards, to enforce the standards, and to adjudicate violations of the standards, as well as to administrate closing down employer operations in the event of imminent dangers. With considerable support from the Republican party, the business community vigorously objected. In the words of Senator Dominick of Colorado, who favored the legislation but supported a "division of responsibilities," the "concentration of authority" advocated by the Democrats was not "balanced" and was "objectionable because concentration of power gives rise to a great potential for abuse" (116 *Cong. Rec.* 37,336 [1970]).

The Democratic view was embodied in the Williams bill, which was adopted by the Senate early in 1970. The Republican approach was taken in the bill sponsored by Congressman William A. Steiger of Wisconsin, also an advocate of OSHA legislation, that passed the House of Representatives. The two bills went to a congressional conference committee late in 1970, and its version became the OSHAct. The conference OSHA bill was a compromise, but the thrust of the legislation was much closer to the stringent Senate bill than to the House version. The Democratic chairman of the House Labor Committee selected representatives to the conference committee who favored the Senate bill, and who no doubt often joined their Senate counterparts in voting on critical issues (Page & O'Brien, 1973). The OSHA law as passed has generally been viewed as a stringent regulatory statute; its subsequent history describes the process by which the courts, the Congress, and the Department of Labor joined in an often uncomfortable alliance to make this new and historic legislation—borrowing the words of Senator Dominick—"workable and effective."

OSHA Program Structure

The statutory structure of the OSHAct is often articulated; therefore, only the basic policy principles underlying the new law will be stated.

UNIVERSAL COVERAGE

The OSHAct applies to all private employers, without exception. Federal employees and state and local employees in states with approved plans are covered by separate occupational safety and health programs. A limited number of particular working conditions subject to the enforcement of occupational safety and health standards of other federal agencies such as the Coast Guard are also not covered by the OSHAct.

EMPLOYER OBLIGATIONS

The employer's obligation to provide safe and healthful working conditions is defined primarily by means of standards promulgated by the secretary. The standards are generally promulgated after public rulemaking proceedings designed to elicit data and views on which these standards are based. The standards define employer obligations prospectively and in considerable detail. To the extent that a hazard is not covered by a standard, the employer must comply with the general duty obligation to provide a workplace "free from recognized hazards likely to cause death or serious physical harm."

ENFORCEMENT

Enforcement of the OSHAct through workplace inspections, citations, and assessment of civil penalties is designed to achieve safe and healthful workplaces in two significant ways:

- With respect to workplaces actually inspected, OSHA imposes legally enforceable abatement requirements and conducts follow-up inspections. These are expected to bring about neutralization of hazards at that workplace. The OSHA system for determining priorities for inspection, usually called "worst-first," should thus result in substantial elimination of hazards in the most dangerous workplaces.
- As for other workplaces, the enforcement program is intended to constitute an incentive to employers to abate hazards without regard to whether an inspection takes place. Two elements in the statutory structure are particularly designed to achieve this result: Sanctions are imposed when violations are disclosed at the first inspection, and no advance notice is given of workplace inspections.

EMPLOYEE PARTICIPATION

The OSHAct is primarily designed to protect workers, and the statute gives them a crucial role in virtually every aspect of the program. For example, an employee representative has the right to request a workplace inspection, to participate in the walkaround inspection, to participate in adjudicatory and court review proceedings and rulemaking hearings, and, significantly, to be free from employer reprisal for the exercise of rights protected under the act. Regulatory requirements have also been imposed on employers to ensure that employees are informed of workplace hazards; this has been called worker right to know.

CHECKS AND BALANCES

Reflecting the concern of Congress that the OSHA program be balanced, the act contains both broad agency authority and constraints on that authority. Discretion is given to the secretary to issue occupational safety and health standards; however, these standards can generally be issued only if the agency follows detailed rulemaking proceedings. Specific criteria are set forth in the statute, notably in sections 6(b)(5) and (7), for the content of OSHA health standards, which must be based on the best available evidence. All standards are subject to court of appeals review based on the record in the rulemaking proceeding. Similarly, OSHA enforcement actions can be contested and are adjudicated before a neutral and independent commission; employees have the right to intervene and protect their interest in these adjudicatory proceedings. Other constraints on the agency, though not explicitly stated in the act, are implicit in our governmental system. Noteworthy among them is the right of an employer to refuse a workplace inspection unless preceded by a warrant based on probable cause. Congressional and White House scrutiny of OSHA implementation of the act, particularly in the area of standards development, has been pervasive.

ROLE OF THE STATES

The OSHA program is primarily a federal program. After a brief transition period, state occupational safety and health enforcement was preempted. However, the act assigns a role to the states to develop their individual OSHA programs, which are supported by 50 percent federal funding; the state programs must be "at least as effective as" the federal program and are subject to continuing federal monitoring and evaluation. The history of OSHA has been replete with sharp controversies over the proper role of the states in the enforcement of the OSHAct.

INFORMATION AND DATA

Congress was acutely aware of the inadequacy of the then available fund of information on occupational injuries and illnesses. In order to more accurately determine injury and illness rates, the act mandates that employers maintain accurate records on all but minor work-related injuries and illnesses, and that they periodically report that information. Furthermore, OSHA was required to develop "an effective program of collection, compilation, and analysis" of occupational safety and health statistics. This responsibility was assigned to the Bureau of Labor Statistics (BLS) in the Department of Labor, which publishes annually the results of its statistical survey of occupation-related injuries and illnesses.

TRAINING AND EDUCATION

In addition to its power to impose sanctions, OSHA has a wide range of authority that includes education, training, and consultation, which is designed to elicit voluntary employer and employee cooperation in bringing about safe and healthful workplaces. These voluntary programs have been undertaken by OSHA throughout its history and have received special emphasis during the administration of President Reagan. The program of enforcement-free workplace consultation visits, which has been financed mostly by OSHA and operated by the states, has been particularly important.

1971–1973: EARLY AGENCY ACTIVITIES

The New Agency

The secretary of labor first created an agency within the Department—the Occupational Safety and Health Administration—to implement the new program. Its head, OSHA's first assistant secretary, was George C. Guenther, who served until January 1973. Guenther had formerly been head of the Department of Labor's Bureau of Labor Standards, which had responsibility for administering the pre-OSHA occupational safety and health programs under the Walsh–Healey Act, the Longshoremen and Harbor Workers Act, and related legislation. An administrative structure was established for enforcing the act; this included 10 regional offices and 49 area offices, staffed with compliance officers assigned to the area offices who were responsible for conducting workplace inspections. At that time, most of the OSHA inspectors had expertise in the area of safety. In June 1973, OSHA had 456 safety inspectors and 68 industrial hygienists. Not unexpectedly, the bulk

of OSHA inspection activity, 93.4 percent in fiscal year 1973, was safety related (OTA, 1985). This reflected the primary emphasis that had been placed in the past, both in and out of government, on industrial accidents, about which a great deal more was known than work-related illnesses. It would be another five years, when Assistant Secretaries Corn and Bingham shifted OSHA's emphasis to health hazards, before industrial hygiene inspectors constituted a significant portion of OSHA's compliance staff.

Compliance Activity Commences

A regulatory framework for OSHA activity was established in the first two years of OSHA's existence. Two major regulations were issued in 1972 after public comment. The first, known as Part 1903, dealt with agency inspection procedures (29 *CFR* 1903). The OSHA statute sets forth the basic outline for OSHA enforcement activity. The inspection regulations fleshed out inspection procedures in numerous ways and provided interpretations of key provisions. The regulations in Part 1903 have remained substantially intact throughout the history of OSHA.

Another major element in OSHA's regulatory framework was the first *Compliance Manual*, originally issued in April 1971 and periodically revised thereafter (OSHA, 1972). It is currently titled the *Field Inspection Reference Manual* (FIRM) (see Chapter 28). Although intended as instructions to field staff for implementing the OSHA program, the *Compliance Manual* from the start was a public document and, in practice, has constituted the primary means by which the agency advised interested parties of its policies in administering the statute. Many interpretations of statutory terms—what constitutes a serious, willful, and repeated violation—are included in the manual; a general definition of imminent danger is also included.

A particularly crucial component of OSHA's *Compliance Manual* was the establishment of inspection priorities. Under the act, OSHA has general inspection authority; however, inspections are mandated only in response to certain written employee complaints. It has therefore been essential for OSHA to define the criteria for its selecting for inspection by its limited compliance resources among the approximately 5 million workplaces.

In its first *Compliance Manual*, OSHA gave instructions on what it called compliance programming. The first priority (after dealing with imminent dangers) was to investigate workplaces where fatalities or catastrophes had occurred. The second priority was response to employee complaints. The third priority was the special hazard elimination programs, which included target industries and health hazards. These priorities brought OSHA inspectors to the most hazardous workplaces—those hazardous as determined in part in the annual statistical surveys of the BLS.

Fourth, to the extent resources were available, OSHA said it would conduct inspections of all other workplaces in order to make clear that the act's obligations are applicable to all private employers. (The latter two categories are usually called programmed inspections [OSHA, 1972, Chapter 4]). Although these broad priority categories have remained substantially the same since 1972, they have been modified in detail in many respects, particularly in regard to agency response to complaints. Considerable controversy later developed, in Congress and elsewhere, as to whether employers with above-average safety records should be exempt from inspection activity.

Field staff were required to report regularly on enforcement activity to OSHA's national office in Washington. One of the required statistical reports is the number and type of OSHA inspections. In fiscal year 1973, for example, OSHA conducted about 48,000 inspections; 5.1 percent of these were fatality/catastrophe inspections, 13.7 percent were complaint inspections, 66.5 percent were programmed inspections (target-industry and general-industry inspections), and follow-up inspections in workplaces where violations had been found constituted 14.7 percent. Since then, the total number of inspections grew to a high of about 90,000 in fiscal year 1974, leveling to about 60,000 or fewer after 1977, which may reflect the new emphasis on more time-consuming health inspections. Although the number of fatality/catastrophe inspections has remained fairly constant over the years, there have been significant variations in the number of complaint inspections, resulting from important agency policy changes either emphasizing or deemphasizing complaint inspections. A significant deemphasis in follow-up inspections occurred after 1981 (OTA, 1985).

The enforcement program began at the end of August 1971, when OSHA's newly adopted standards came into effect. The first OSHA citation was issued at the beginning of May; it was a general duty violation based on excessive employee exposure to mercury. During the remainder of the calendar year, 9,507 citations were issued, with proposed penalties amounting to $737,486. In 1972, the number of issued citations increased to 23,900, and the amount of the proposed penalties was more than $3 million (*The President's Report on Occupational Safety and Health*, May 1972, Dec. 1973).

Start-Up Standards

One of OSHA's most important tasks after the act became effective was to issue standards that would provide the agency with a basis for promptly commencing its enforcement program. Congress gave the agency authority under section 6(a) to promulgate certain standards without rulemaking—that is, without the delays inherent in public comment proceedings. These standards have been called start-up standards and included national consensus standards and established federal standards, both of which had gone through at least some public comment process before they were issued. The OSHA quickly—many have said too quickly—promulgated these standards, and on May 29, 1971, barely a month after the act's effective date, OSHA

issued a large body of these start-up standards. Most were in the safety area and were taken from standards issued by the American National Standards Institute (ANSI) and the National Fire Protection Association (NFPA), both determined by Congress to be national consensus organizations; others were pre-OSHA standards issued under the Walsh–Healey Act, the Longshoremen's and Harbor Workers' Compensation Act, and the Construction Safety Act, all of which had already gone through rulemaking proceedings. Some health standards were issued in 1971. Among them were the Threshold Limit Value® (TLV) levels of the American Conference of Governmental Industrial Hygienists (ACGIH) for about 400 substances, which had become established federal standards under the Walsh–Healey Act. These contained no more than the Permissible Exposure Limit (PEL) and a requirement for implementation of engineering and protective-equipment controls to reach the limit. But these limits were often based on inadequate information; in 1970, Congress recognized that the standards "may not be as effective and up-to-date as desirable," and that they would provide only a "minimum level of health and safety" (S. Rep. No. 1282, *91st Cong., 2nd Sess.* 6 [1970]).

There is no question that OSHA's adoption of start-up standards in 1971 got enforcement off to a rapid start. Even today, the bulk of OSHA safety standards appearing in the *Code of Federal Regulations* is the original material that was issued at the start of the program. But OSHA's hasty action led to no end of controversy and criticism of the young regulatory agency. Litigation ensued when OSHA began to enforce its national consensus safety standards, and many citations and penalties were reversed by the Review Commission and the courts. Indeed, one of the most outspoken critics of OSHA's start-up standards was Robert D. Moran, chairman of the Review Commission, who argued that these standards "violate the spirit and purpose of the Act" (Moran, 1976, pp. 19-20). Even the president of the AFL-CIO, testifying many years later, said, "Because of the hue and cry over these 'nit-picking' aspects of the program, the more serious and important goals of the OSHA program became lost in a morass of largely unintelligible debate and political animosity" (*Oversight on the Administration of the Occupational Safety and Health Act, 1980: Hearings Before the Senate Comm. on Labor and Human Resources*, 96th Cong., 2nd Sess. 730–731 [1980] [testimony of Lane Kirkland, president of the AFL–CIO]). Largely in response to the criticism, a presidential task force was organized in 1976 to develop a "model approach to safety standards." The task force reported a year later that OSHA should avoid design or specification requirements, and recommended a performance approach, by means of which employers would have had considerable flexibility to achieve the safety goals of the standard "by any appropriate means" (MacAvoy, 1977, pp. 17–21). The OSHA Appropriations Act in 1976 directed the agency to undertake a "review and simplification" of existing standards and to eliminate "nuisance" standards (*Department of Labor and Health, Education and Welfare Appropriations Act of 1976*, Pub. L. No. 94-206, 90 Stat. 3 [1976]).

The pressure continued to mount, and in 1978, after receiving public comment, OSHA eliminated about 600 safety standards, using seven criteria for determining which should be revoked; among those deleted were "obsolete" or "inconsequential" standards and those "encumbered by unnecessary detail" (43 *FR* 49, 726 [1978]). OSHA also undertook a broad revision of all its national consensus standards, a project that has moved slowly, with only the standards on fire protection and electrical hazards revised by 1985. Other issues arising from the initial promulgation continued to receive OSHA's attention. One of these was whether so-called "should" standards—those stating that employers "should" take a particular action rather than "shall" do so—were mandatory in effect. This issue was litigated extensively and was not resolved until February 1984, when OSHA revoked a group of its "should" standards (49 *FR* 5318 [1984]).

Regulating Asbestos

In enacting OSHA, Congress was well aware of the dangers of employee exposure to asbestos fibers. The Senate Labor Committee in its 1970 report described asbestos as "another material which continues to destroy lives of workers," noting that as many as 3.5 million workers are at risk of asbestosis, pulmonary cancer, and mesothelioma as a result of asbestos exposure (S. Rep. No. 1282, *91st Cong., 2nd Sess.* 2–4 [1970]). In 1971 OSHA adopted, as an established federal standard, the Walsh-Healey Asbestos Standard, requiring the implementation of engineering controls to achieve a PEL of 12 fibers per cubic centimeter of air. However, it was immediately apparent that this standard provided inadequate protection. Several months after the effective date of the asbestos start-up standard, on December 7, 1971, OSHA invoked its emergency authority to issue an emergency temporary standard (ETS) for asbestos. The ETS mandated, effective immediately, a 5-fiber per cubic centimeter of air 8-hour time-weighted average (TWA), with a 10-fiber per cubic centimeter of air ceiling for any 15-minute period (36 *FR* 23,207 [1971]).

The standard was based on OSHA's finding that there was a "grave danger" to employees from asbestos exposure. Unlike many later OSHA emergency standards that were challenged, and the challenges sustained, the asbestos ETS was not challenged and remained in effect for the entire six-month period. In June 1972, after receiving written comment and testimony at a public hearing, OSHA issued a permanent asbestos standard. In its preamble to the standard—which explains the basis for the standard—OSHA asserted that there was no dispute that exposure to asbestos is "causally related" to cancers and asbestosis; the only issue, it said, was the specific level below which exposure is safe. This was an issue because the agency did not have "accurate measures" of the levels of exposure occurring

20–30 years ago that caused the disease. However, OSHA concluded that in view of the undisputed "grave consequences" of exposure to asbestos fibers, it is essential that the exposure be regulated "on the basis of the best evidence available now, even though it may not be as good as scientifically desirable" (37 *FR* 11,318 [1972]). The agency therefore determined that the PEL should be set at 2 fibers per cubic centimeter of air. However, concluding that "many work operations" would meet "varying degrees of difficulty," such as the necessity for extensive redesign and relocation of equipment, in complying with the 2-fiber per cubic centimeter of air standard, OSHA delayed the effective date for four years, applying a less strict 5-fiber standard in the interim.

The AFL–CIO's Industrial Union Department challenged the standard in the Court of Appeals for the District of Columbia Circuit. Among other provisions, the union attacked the delay in applying the stricter PEL. The court's decision in the case was a landmark in the development of OSHA law. It affirmed OSHA's decision to adopt a 2-fiber per cubic centimeter standard. In much-quoted language, the court, in an opinion by Judge Carl McGowan, recognized that some of the questions involved in OSHA standards development are "on the frontiers of scientific knowledge," and therefore not susceptible to precise factual determination. Court review, therefore, cannot be the factual type of review that is typically undertaken by the courts, but rather must be deferential to the agency, calculated only "to negate the dangers of arbitrariness and irrationality." In the matter of asbestos, the court said, the choice of a lower level was "doubtless sound," inasmuch "as the protection of the health of employees is the overriding concern of OSHA" (*Industrial Union Department v. Hodgson*, 499 F.2d 467, 478 [D.C. Cir. 1974]).

However, although it affirmed the agency's 2-fiber per cubic centimeter of air level, the court rejected OSHA's delay of the effective date. The court granted that "feasibility" considerations, both economic and technical, can play a role in OSHA decision making, but OSHA had not shown in the record why it was necessary to impose an across-the-board delay in needed protection for workers in all industries. The case was remanded to OSHA for further development of a record on the feasibility of the lower PELs in specific industries. The language of the court on the feasibility issue has also served as a significant precedent for later decisions on OSHA standards. "Practical considerations can temper protective requirements," Judge McGowan said. At the same time, standards may be economically feasible "even though, from the standpoint of employers, they are financially burdensome and affect profit margins adversely." However, the court determined that a standard was not feasible if it required "protective devices unavailable under existing technology or by making financial viability generally impossible" (*Industrial Union Department v. Hodgson*, 499 F.2d 467, 478 [D.C. Cir. 1974]).

Involving the States

The dissatisfaction of organized labor with OSHA's asbestos standard was exceeded in intensity by the controversy engendered by the agency's initial policy in the area of state plans. The act contains a detailed scheme defining the OSHA relationship between the federal government and the states. Primary authority was assigned to the federal agency; the states were preempted except if they submitted "at least as effective" plans that are approved by OSHA and found in practice to be equally effective. Finally, in order to prevent preemption of ongoing state programs while the states were still developing plans for submission, section 18(h) authorized two-year agreements permitting continued state enforcement.

OSHA acted quickly to encourage state participation in the OSHA program. The secretary of labor quickly wrote to the governors, urging the states to enter into section 18(h) agreements and to submit "at least as effective" plans. All but three states accepted the secretary's invitation and entered into section 18(h) agreements. By the end of 1972, 44 states, the District of Columbia, and four territories had submitted plans. However, it was apparent that these plans as submitted did not meet the statutory criteria for equal effectiveness. Thus, many states lacked occupational safety and health-enabling statutes that could provide authority for their state OSHA programs. To meet this problem, apparently unanticipated by Congress, and "to allow the transition that states must undergo to upgrade an existing program," OSHA developed a new concept—the developmental plan—in its State Plan Regulations (Part 1902). This authorized approval of state plans would trigger 50 percent federal funding granted on the basis of commitments by the states to effectively meet goals in the future, generally within three years, even though, on submission, the plans were conceded to be not equally effective (29 *CFR* 1902.2).

Organized labor was skeptical from the start about state efforts, arguing before the committees considering OSHA bills that state OSHA programs were largely understaffed and ineffective. When the developmental concept appeared by means of OSHA interpretation in 1971, it was vigorously opposed by the unions. The main forum for debate was the National Advisory Committee on Occupational Safety and Health (NACOSH), created by the act, where Jack J. Sheehan, legislative representative of the United Steelworkers of America, said, "On the developmental plan, it's a non-plan as far as I can understand it" (Proc. NACOSH, Sept. 24, 1971, pp. 119–126).

The debate over developmental plans led to further debate on OSHA's attempt to extend the effective period of section 18(h) agreements by means of so-called temporary orders. These orders were even more "temporary" than OSHA planned, because in January 1973 a federal district court found them beyond OSHA authority. By the end of 1972, only three plans—those of South Carolina, Oregon, and Montana—had been approved. In explaining the need

for temporary orders, Assistant Secretary George Guenther argued that according to an "absolutely strict interpretation," after 1972 there would be a "protection gap" for employees in states with plans pending approval. The temporary orders would close the gap by allowing state enforcement for an additional six months (Proc. NACOSH, Nov. 16, 1972, pp. 44–46). Judge Barrington Parker did not find this policy imperative sufficiently compelling and refused to approve OSHA's expansive interpretation of its authority. Noting congressional and union objections to temporary orders, Judge Parker relied particularly on the "express language of the Act, which mandated exclusive federal jurisdiction after December 28, 1972"; he also took the position that even without temporary orders, state OSHA jurisdictions would not be "seriously" disrupted, which turned out to be the case (*AFL–CIO v. Hodgson*, 1971–1973 OSHD [CCH] ¶ 15,353 [D.D.C., 1973]). OSHA did not pursue an appeal of Judge Parker's decision, and temporary orders were abandoned.

Involving Workers

The act pervasively provides for the participation of employees in the OSHA program. The right of employees or their representatives to request an inspection and their right to participate in the physical inspection of the workplace are foremost. Under section 8(f)(1), OSHA must conduct an inspection if an employee or representative files a written complaint alleging that a hazard is threatening physical harm or that there is an imminent danger, and OSHA determines that there are "reasonable grounds" to believe there is merit to the complaint. Early on, an issue arose concerning OSHA's response to complaints that did not meet the formality requirements of the act. These, usually known as informal complaints, include oral communications by employees—such as telephone calls to an area office—alleging hazardous workplace conditions. OSHA, emphasizing its limited inspection resources, determined in its first *Compliance Manual* that, as a general rule, informal complaints would not trigger workplace inspections except in situations apparently involving imminent dangers (*OSHA Compliance Manual*, Jan. 1972, Chapter 6). This inspection policy continued essentially unchanged for the next four years, until the traumatic "Kepone incident," to be discussed later in this chapter, forced OSHA to a major reversal of its policy on informal complaints.

The right of employees to participate in the physical inspection is known as the walkaround right. In reporting favorably on the OSHA bill in 1970, the Senate Labor Committee observed that under pre-OSHA laws, "workers tend[ed] to be cynical regarding the thoroughness and efficacy" of inspections, because they were usually not advised that an inspection was taking place. The walkaround right was therefore added to "provide an appropriate degree of involvement of employees themselves in the physical inspections of their own places of employment" (S. Rep. No. 1281, 91st Cong., 2nd Sess. 11-12 [1970]). The question that arose almost immediately was, Are employees selected as representatives in the walkaround entitled to the wages they would otherwise have received if they had continued actual work? In a proceeding involving an inspection of the Mobil Oil Company, the Oil, Chemical and Atomic Workers Union complained that pay was withheld from its members, thus interfering with a basic statutory right. The solicitor of labor rejected the claim, deciding that time spent in accompanying an inspector did not constitute hours worked, and therefore no discrimination had taken place. The Court of Appeals for the District of Columbia upheld the solicitor's view in a related case involving the Fair Labor Standards Act (*Leone v. Mobil Oil Corp.*, 523 F.2d 1153 [D.C. Cir. 1975]). The OSHA policy remained the same until 1977, when it was reexamined and reversed by Assistant Secretary Bingham.

Many statutes, both federal and state, contain whistleblower provisions protecting the exercise by individuals of their protected rights against reprisal and retaliation. Section 11(c) of the OSHAct is a whistle-blower provision: It prohibits discrimination in conditions against employees "because of the exercise of any rights afforded by the Act." Specifically mentioned are the protected rights to file complaints, to institute OSHA proceedings, and to testify at those proceedings. In its initial interpretation of the provision, OSHA said that the provision also protected "other rights [that] exist by necessary implication." That interpretation confronted a particularly difficult issue: whether an employer could discharge or discipline an employee for refusing to work in particularly dangerous circumstances. OSHA expansively interpreted the act and determined that an employee was protected against discipline if "with no reasonable alternative" he or she "in good faith" refuses to expose himself/herself to imminently dangerous conditions (29 *CFR* 1977.12).

Injury and Illness Rates

One of Congress's important goals in enacting OSHA legislation in 1970 was to improve the reliability of the work-injury and work-illness data. Although the BLS had been collecting and publishing these data for more than 30 years, there were serious limitations on the usefulness of the statistics that were based on the Z.16.1 ANSI standard, the *American Standard Method of Measuring and Recording Work Injury Experience*. Only disabling injuries had been counted in the injury rates; occupational illnesses were seldom, if ever, recorded, except in the most obvious and extreme cases, and the information was limited by its dependence on voluntary reports from employers.

The OSHA statute required the secretary of labor to issue regulations requiring employers "to maintain accurate records of, and to make periodic reports on, work-related deaths, injuries and illnesses other than minor injuries requiring only first aid treatment and which do not involve medical treatment, loss of consciousness, restriction of work or motion or transfer to another job." The secretary was also

required "to develop and maintain an effective program of collection, compilation, and analysis of occupational safety and health statistics." Soon after the act was passed, the secretary directed the BLS to continue to collect and publish work-injury statistics under the new law. Mandatory record-keeping regulations (Part 1906) were adopted by OSHA and published on July 2, 1971, following public written comment, advice and consultation by an interagency group, and a public hearing held by the Office of Management and Budget (OMB). Under the regulations, employers were required to maintain a log of occupational injuries and illnesses, a supplemental record containing more detailed information on each injury and illness, and a yearly statistical summary of injuries and illnesses. These documents were maintained by all employers at individual establishments, but only a statistical sample of employers was required to report to BLS on injury and illness experience.

The BLS's first full-year survey in 1972 included data for all employments outside of farms and government (which were separately surveyed) and showed almost 5.7 million recordable work-related injuries and illnesses; that is, one out of every 10 workers experienced a job-related injury or illness. Then, as it has in each survey since 1972, BLS emphasized that "underreporting of occupational illnesses is prevalent due to problems of identification and measurement." These problems include "lack of facilities and trained medical personnel for proper diagnosis; long latency periods thwarting timely detection; questions of occupational illness coverage under workers' compensation; and factors outside the work environment that cloud the work relationship concept." In addition to reporting on numbers of injuries and illnesses, BLS also reports on incidence rates—that is, the number of injuries and illnesses per 100 full-time employees. In 1972, the incidence rate for all recordable cases was 10.9. The incidence rate for lost-workday cases was 3.3, and for nonfatal cases without lost workdays, it was 7.6 (*The President's Report on Occupational Safety and Health*, Dec. 1973).

Additional OSHA activities during this period included establishing a training institute in Rosemont, Illinois (now located in Des Plaines, Illinois). The institute opened in January 1972 to provide training primarily for federal and state inspection staff and employees in the private sector. On July 28, 1971, President Nixon signed Executive Order 11,612, implementing section 19 of the act and setting up the framework for the safety and health program for federal employees. OSHA's role in the federal safety program was essentially advisory; primary responsibility for carrying out the requirements of the law and the executive order was assigned to the individual federal agency heads. Finally, OSHA embarked on a program of cooperation with 28 other federal agencies that had authority relating to occupational safety and health in the private sector. Despite an agreement with the Department of Transportation in May 1972 that was designed to avoid duplication in the handling of complaints in the railroad industry, it became clear very quickly that major jurisdictional disagreements among the various federal agencies were emerging that would be difficult to resolve.

1973–1976: THE AGENCY CONTINUES TO GROW

OSHA's First Transition

George C. Guenther left office in January 1973, at the beginning of President Nixon's second term. After a brief hiatus, John H. Stender, a former union official and a Republican legislator from the state of Washington, became assistant secretary of OSHA. He served until July 1975 in an often stormy term of office. There was no assistant secretary from June until December 2, 1975, when Dr. Morton Corn, who had been a professor of industrial hygiene and engineering at the University of Pittsburgh, took office. As the first health professional to head OSHA, Dr. Corn brought about major changes, emphasizing professionalism and effecting a major reorientation toward health regulation and enforcement. Dr. Corn left office in January 1977, when the newly elected President Jimmy Carter chose Dr. Eula Bingham, also a health professional, as assistant secretary.

During the period between 1973 and 1976, OSHA continued to grow, both in size and in the magnitude of the controversy it engendered. The OSHA budget in fiscal year 1972 in current dollars was 33.9 million; by fiscal 1977 it was $130.2 million. (As adjusted for inflation, the growth rate, of course, was less marked: $33.9 million in 1972 and $90.0 million in 1977.) The OSHA inspection staff also grew. At the end of 1972, the field enforcement staff included 456 compliance officers and 68 industrial hygienists. Almost all compliance officer positions authorized for fiscal year 1976 were industrial hygienists, so that in December 1976 there were 358 hygienists in OSHA, or 27 percent of the total staff (*The President's Report on Occupational Safety and Health*, Dec. 1976).

There were parallel increases in the number of OSHA inspections; in particular, Assistant Secretary Stender emphasized the importance of numbers of inspections. In fiscal year 1973, there were 48,409 establishment inspections; by fiscal 1976 the number had grown to 90,482.

The total number of OSHA inspections was reduced in fiscal 1977, largely as a result of the new emphasis on health enforcement that was introduced by Dr. Morton Corn. In fiscal 1976, 8.4 percent of OSHA inspections were listed as health inspections; in fiscal 1977, 15.2 percent, and in fiscal 1978 (the beginning of the administration of Dr. Bingham) the number of health inspections grew further, to 18.6 percent. Health inspections are typically far more time-consuming, requiring, among other things, calibration of equipment, monitoring of workplace atmospheres, and collection and analysis of monitoring results. In 1977, OSHA separated from its *Compliance Manual*, which had come to be known as the *Field Operations Manual* (*FOM*), a detailed

instructions manual for health inspections—then named the *Industrial Hygiene Field Operations Manual* (*IHFOM*). The IHFOM specifies the technical procedures for making an industrial hygiene inspection to ensure uniformity. OSHA also embarked on a three-year apprenticeship program for entry-level health compliance officers.

The Kepone Incident

The basic OSHA priorities for selecting workplaces for inspection remained basically the same during the Stender and Corn Administrations. Special emphasis programs, focusing on inspections of specific hazardous industries, were adopted. In March 1973, the emphasis was placed on trenching and excavation inspections; a new program was instituted in 1975, called the National Emphasis Program (NEP), targeting foundries for inspection. The purpose of these programs was to combine a variety of OSHA resources including training and education, consultation, and enforcement in concentrating on a single high-hazard area. The most important change in OSHA's inspection priority system was its major modification in response to employee complaints, which took place in 1976 as a result of the "Kepone incident." In September 1974, OSHA received a complaint from a former employee of Life Science Products Company of Hopewell, Virginia, a chemical-manufacturing company, alleging his exposure to pesticide fumes and dust. The OSHA area office did not conduct an inspection of the facility because of the complaint's informality, treating it instead as a discrimination complaint under section 11(c). The matter rested there for about 10 months, when it became known that Life Science employees had been massively exposed to a pesticide, Kepone, which caused serious illness in seven of these employees. The facility was quickly closed down by the state of Virginia, and it became known that pervasive ecological damage had been caused by the company's irresponsible and unlawful disposal of Kepone into the James River.

The great human and environmental damage, caused—on the surface, at least—by OSHA's failure to inspect, led to great public outrage. In March 1976 a subcommittee of the House Labor Committee held a hearing in Hopewell, Virginia, on the Kepone incident. Dr. Corn had just assumed office, and he was thoroughly and angrily questioned on OSHA's handling of the Kepone complaint, which had preceded his association with OSHA. Although OSHA sometimes was blamed for workplace accidents with little or no justification, the agency's performance in the Kepone matter required much explanation. Dr. Corn wrote to Chairman Gaydos, saying that the "episode has pointed up a distinct need for improvements in OSHA's response to employee complaints of hazardous working conditions" (Corn letter, 1976). Soon thereafter, OSHA revised its field instructions, instructing staff to conduct a workplace inspection "whenever information comes to the attention of the Area Director without regard to its source and without regard to whether it meets the formality requirements of section 8(f), indicating that safety or health hazards exist at a workplace." The directive also shortened the time frame for complaint responses: no more than 24 hours for imminent dangers, 3 days for serious violations, and 7 working days for nonserious violations (OSHA Field Information Memo No. 76-9, 1976). The Kepone incident also solidified Dr. Corn's intention to focus a greater portion of OSHA's resources on health regulation.

It was expected that the new policy would substantially increase the number of complaint inspections. In fiscal year 1976, complaints were 10.2 percent of total inspections; one year later, complaint inspections constituted 32.4 percent (19,415 out of 60,004 inspections). There were similar high percentages of complaint inspections for the next two years. The impact that this new emphasis had on OSHA enforcement activity was not entirely anticipated, however. In December 1977 OSHA said that the number of complaints received and investigated "overtaxed the resources available—introduced complaint backlogs, reduced inspection activity at some field offices in several important safety and health programs, and severely decimated planned regional inspection programs" (OSHA Prog. Dir. No. 200-69 [1977]). The complaint policy was criticized in a 1979 report of the comptroller general, as will be discussed later, and was significantly modified by Dr. Bingham in 1979.

With the increase in OSHA inspections, there were substantial increases in the number of OSHA citations issued, the numbers of violations of all kinds, and the rate of employer contest of citations and penalties. For example, in fiscal year 1973, 3.2 percent of inspections resulted in serious violations (1,535 violations); by fiscal year 1977 this increased to 18.5 percent of inspections (11,092 violations). The increase in the number of serious citations resulted in part from a series of issue papers by the General Accounting Office (GAO) at the request of the Senate Committee of Labor and Human Resources, which criticized OSHA for its citation policy (*OSHA Review, 1974: Hearings Before the Subcomm. on Labor of the Senate Comm. on Labor and Public Welfare*, 93rd Cong., 2nd Sess., apps. 941–1238 [1974]). The percentages of OSHA inspections finding willful and repeated violations, which are subject to penalties of up to $10,000, were substantially smaller (in fiscal 1977, 0.3 percent willful violations and 3.9 percent repeated violations), but they too increased over the four-year period. The contest rate almost tripled between 1973 and 1977, reflecting the growing adversarial quality of the OSHA program. During 1975, OSHA implemented a comprehensive field performance evaluation system, establishing qualitative and quantitative criteria for federal field activities (*The President's Report on Occupational Safety and Health*, 1975, pp. 49–53).

OSHA in Court

With increased litigation over citations and penalties, the OSHA enforcement case law evolved at a rapid rate. Some of the proceedings challenged the constitutionality of the

enforcement scheme. The issue was decided favorably to OSHA in 1977 in *Atlas Roofing Company Inc. v. OSHRC*, 430 U.S. 442 (1977). In this major constitutional decision, the U.S. Supreme Court held that Congress could constitutionally establish a flexible administrative procedure for the imposition of civil penalties, even though no jury trial was provided.

The general duty clause also resulted in numerous court decisions. In a major case decided in 1974, the Court of Appeals for the Eighth Circuit, *American Smelting and Refining Company v. OSHRC*, 501 F.2d 504 (8th Cir. 1974), held that high levels of airborne concentrations of lead were a "recognized" hazard under section 5(a)(1), even though they could not be detected except through the use of monitoring equipment. Although a lead standard was soon to become effective, and the general duty clause no longer applied to lead hazards, the basic principle had a major impact. In *National Realty and Construction Co. v. OSHRC*, 489 F.2d 1257 (D.C. Cir. 1973), decided a year before by the Court of Appeals for the District of Columbia Circuit, several principles of general duty law were set forth:

- In determining whether a hazard was "recognized," the standard "would be the common knowledge of safety experts who were familiar with the circumstances of the industry or activity in question."
- A hazard was "likely to cause" death or serious physical harm if the result "could eventuate" "upon other than a freakish or utterly implausible concurrence of circumstances."
- The general duty clause imposes sanctions only on "preventable hazards"; hazardous conduct by employees is not "preventable" "if it is so idiosyncratic in motive or means that conscientious employers familiar with the industry could not take it into account in prescribing a safety program."

This last issue, known as the employee misconduct defense, followed OSHA in its commission and court litigation throughout the agency's history.

The increased court litigation, involving both citations and penalties and, as we shall see, litigation on the review of OSHA standards, raised a critical question as to which group of attorneys would be responsible for this litigation. The act stated that OSHA litigation (except for litigation in the U.S. Supreme Court) would be handled by Department of Labor attorneys in the Office of the Solicitor, "subject to the direction and control of the Attorney General." Almost immediately after the effective date of the act, a dispute arose as to the extent of this Department of Justice "direction and control." The Labor Department claimed that its attorneys, who were experienced and expert in OSHA affairs, were more qualified to handle its litigation with minimum supervision by the Department of Justice. Justice argued, on the other hand, that they were more experienced litigators and that they should handle OSHA litigation, just as they handle most other Executive Department litigation. The Department of Justice's view prevailed at first, causing considerable bad feeling and morale deterioration on the part of OSHA and its attorneys. However, in 1975, an agreement was reached between the Departments of Labor and Justice relating to OSHA and two other enforcement programs, assigning primary litigating authority to the Office of the Solicitor and establishing procedures to determine the rare circumstance when the Department of Justice would become involved. This arrangement has continued to the present time on courts of appeals litigation; Supreme Court litigation continues to be handled by the Solicitor General, and procedures for handling federal district court litigation are normally worked out on a local level between the U.S. attorneys and the regional solicitors' offices.

Disputes over Jurisdiction

OSHA is not the only federal agency with authority on occupational safety and health. Other agencies, notably the Department of Transportation (DOT), also enforce statutes which, although less comprehensive in scope than OSHA, concern worker protection. To avoid duplication of effort of agencies, as well as to ensure that there is no hiatus in protection, section 4(b)(1) of the act provides that OSHA does not apply to "working conditions" with respect to which another federal agency "exercise[s] statutory authority to prescribe or enforce standards or regulations affecting occupational safety or health." The meaning of the provision and the delineation of jurisdiction among agencies have been yet another source of continuing controversy and litigation from the start of the program.

OSHA has construed the section to mean that the exemption from OSHA applies only to specific working conditions as to which another agency exercised its authority; that is, only when the agency issues standards affecting occupational safety and health. The railroad industry, among others, often supported by federal regulatory agencies eager to protect their jurisdictions, argued that section 4(b)(1) provides an "industry exemption" for any industry subject to any occupational safety or health standards. The Review Commission, in 1974, and several courts of appeals, in 1976, rejected the "industry exemption" argument (see, for example, *Southern Railway v. OSHRC*, 539 F.2d 335 [4th Cir.], *cert. denied*, 429 U.S. 999 [1976]), but litigation continued on a variety of related issues under section 4(b)(1). One of those issues was the meaning of *working condition*. The courts split on whether it means physical surroundings or hazards. Another issue was the definition of *exercise;* how much "exercise" does the other federal agency have to undertake to preempt OSHA (see, for example, *Northwest Airlines*, 8 OSHC 1982 [Review Commission, 1980]).

Litigation, it was generally thought, was a poor and expensive way to decide jurisdictional issues, and considerable effort was then invested by the affected agencies to negotiate jurisdictional agreements to clarify to employers and employees which agency was responsible for occupa-

tional safety and health enforcement activity. These agreements were useful in principle, but seldom succeeded in clarifying any jurisdictional issues. In 1972, OSHA's memorandum with the Federal Railroad Administration provided an expeditious method of handling employee complaints in the railroad industry, without attempting to decide jurisdictional questions. However, the agreement was cancelled in 1974 by Assistant Secretary Stender, with no reasons given, and was never renewed. Various agreements were negotiated between OSHA and the U.S. Coast Guard in the DOT in respect to jurisdiction during activities and in the nation's waterways and on the outer continental shelf. In 1983, OSHA conceded authority to the Coast Guard respecting "working conditions of seamen aboard inspected vessels" (48 *FR* 11,365 [1983]). The most successful interagency agreements have been between OSHA and the Department of Interior regarding mine safety, with any remaining jurisdictional issues regarding mines largely resolved when Congress passed the Mine Safety and Health Act of 1977, which broadened the protection of mine employees and transferred enforcement authority to the newly created Mine Safety and Health Administration in the Department of Labor (30 U.S.C. §801 and following).

Anticipating the possibility of disputes in this sensitive area, Congress in the OSHAct directed the agency to submit a report to the Congress within three years of the act's effective date with recommendations to avoid "unnecessary duplication" and to achieve coordination between agencies. The report was filed six years late, and only after OSHA was sued by members of Congress in a federal court for not submitting a report. The report stated that it was satisfied with the status quo, concluding that court opinions will give "an even clearer picture" of jurisdiction, that cooperative efforts among agencies "will continue to expand," and, therefore, that no new legislation was needed (Mintz, 1984, p. 485).

Amendments, Riders, and Oversight

The involvement of Congress with the OSHAct did not end with its enactment in 1970. One of the main techniques available to Congress for monitoring agency performance is the oversight function; this activity includes public hearings and, less formally, contacts, letters, speeches, and telephone calls between members of Congress and staff and the agency, all designed to monitor and influence agency action. The source of Congress's influence is its ultimate authority to amend the act, and, on a continuing basis, its power to control the agency's annual appropriations.

The OSHAct was not amended substantively until 1990, but, as will be discussed, appropriations bills have often been accompanied by legislative riders. Oversight hearings have frequently taken place, often with notable impact on agency activity. Although the Senate and House Labor Committees have primary jurisdiction over OSHA issues, and have frequently conducted oversight hearings, other committees have also held oversight hearings on OSHA. Among these are the Small Business Committees, concerned with the impact of OSHA enforcement on small business, and the Government Operations Committees, which have dealt particularly with regulation of toxic chemicals, hazard communication, and the safety of federal employees.

One of the earliest oversight hearings took place in 1972. A House subcommittee on agricultural labor critically questioned Assistant Secretary Guenther on the absence of OSHA standards to protect farm workers and the lack of enforcement activity in agriculture. At the close of that hearing, Chairman O'Hara said to Guenther in an exercise in understatement, "I want you to know that it is not my intention that you leave this hearing with the impression that we want you to slow down on your enforcement of OSHA in agriculture" (*Farm Workers Occupational Safety and Health: Oversight Hearings Before the Subcomm. on Agricultural Labor of the House Comm. on Education and Labor*, 92nd Cong., 2nd Sess. 15–20 [1972]). At an oversight hearing before the Senate Labor Committee in 1974, Assistant Secretary Stender was pressed on OSHA's delay in setting up a standards advisory committee for coke oven emissions. Stender emphasized his frustration with "bureaucratic delays," an explanation that has often been heard at oversight hearings (*OSHA Review 1974: Hearings Before the Subcomm. on Labor of the Senate Comm. on Labor and Public Welfare*, 93rd Cong., 2nd Sess. 221-250 [1974]). Oversight hearings sometimes lead to committee reports, but often they do not. However, the absence of a report does not mean that the hearing was without impact. After the Kepone hearing, at which Assistant Secretary Corn appeared, OSHA changed its complaint policy, even though no committee report was issued.

Sometimes Congress makes its views known to the agency without a hearing. In 1974, the Senate Labor Committee, with the assistance of the GAO, sent 17 issue papers to OSHA that were critical of various aspects of its enforcement activity. One of these, on classification of violations, suggested that the "number of total serious violations should be far greater than that which have been reported." Shortly thereafter, OSHA issued a "major clarification" of policy on serious violations to regional and area offices in order to "focus attention" of field staff on detecting during inspections hazards involving a significant probability of serious harm (*OSHA Review, 1974: Hearings Before the Subcomm. on Labor of the Senate Comm. on Labor and Public Welfare*, 93rd Cong., 2nd Sess., apps. 941-1238 [1974]). In the next three years, the percentage of serious violations cited by OSHA increased from 2.1 percent of all violations in fiscal year 1976 to 29 percent in fiscal year 1979. Other factors, including new and stricter enforcement policies already discussed, played a part; but congressional pressure, it seems clear, was a crucial factor in making sure that field staff would not overlook the need for serious citations.

The appropriation process is another way that Congress influences the policies of administrative agencies. Appropriations committee reports often give "instructions" to an

agency on how the money should or should not be spent. An example discussed previously was Congress's direction to OSHA in the 1976 appropriations act to undertake a "review and simplification of existing [national consensus] standards" and to eliminate "nuisance" standards.

Congressional interest in expanding OSHA's on-site consultation program was also transmitted to OSHA through the appropriations process. Section 21(c) provides specific authorization for OSHA to provide for the education and training of employers and employees in the recognition, avoidance, and prevention of unsafe and unhealthful working conditions. From the beginning, OSHA undertook programs to educate and train individuals in the private sector in OSHA matters. Some of these programs were conducted by OSHA at its Des Plaines, Illinois, training institute or at regional area offices; others were implemented by OSHA contractors such as the National Safety Council and schools for workers at universities. Numerous educational books, pamphlets, and audiovisual materials were distributed as part of this activity. However, an insistent demand continued for an additional component in employer education: on-site consultation. In these consultations, OSHA would provide information on hazards and controls at the worksite without threat of citation or penalty. Early in its history, OSHA determined that when OSHA personnel enter a workplace and observe hazards, the statute requires that a citation must be issued. This determination elicited criticism, but attempts to amend the OSHAct to authorize on-site consultation were opposed by unions and were not enacted.

States with approved plans generally included on-site consultation programs in their plans (the legal interpretation did not apply to the states), and in 1974 Congressman William A. Steiger, one of the main sponsors of the act in 1970, sponsored an amendment to the OSHA appropriations bill that would authorize additional funds for the specific purpose of financing agreements between OSHA and states without approved plans for on-site consultation. The funds were appropriated and OSHA entered agreements with 12 states, providing 50 percent federal financing for the on-site consultation. The idea was politically attractive, and the Senate Appropriations Committee later directed OSHA to increase the level of funding; OSHA responded, amending its regulations to provide 90 percent financing of these agreements. By 1980, on-site consultation had been made available to employers in all states, either through state plans, through agreements between OSHA and states without plans, or, in limited instances, by private consultants (*Oversight on the Administration of the OSHAct: Hearings Before the Senate Comm. on Labor and Human Resources*, 96th Cong., 2nd Sess., Pt. 1 at 24 [1980] [Testimony of Basil Whiting, deputy assistant secretary of OSHA]).

More commonly, the appropriations process is used by Congress as a check on the agency, through the enactment of limitations on the expenditure of funds—so-called limitations riders. Although the rules of the Congress restrict use of appropriations riders to some extent, in practice they are often introduced and enacted and provide a potent weapon for members of Congress to control agency action without resorting to the formal amendment process. This means that limitations riders are not preceded by committee hearings held by the standing committee with jurisdiction over the statute (in the case of OSHA, the labor committees), which are typically opposed to limitation of agency authority. Often, even the appropriations committee does not consider the rider, which is introduced on the floor. Finally, the pressure to enact appropriations laws is often a strong impetus for Congress to accept the riders. As early as 1972, riders limiting OSHA enforcement activity were passed by one or both houses of Congress, but for a variety of reasons never became law. In 1974, a rider was enacted exempting employers with 10 or fewer employees from OSHA's record-keeping requirements. The provision was incorporated into OSHA regulations and dropped from the appropriation law (29 *CFR* 1904.15).

The breakthrough in OSHA riders took place in 1976, when two major riders were passed. The first exempted small farms with 10 or fewer employees from OSHA enforcement. This rider was Congress' reaction to OSHA's proposal to regulate field sanitation (the history of OSHA's regulation of field sanitation will be discussed later in this chapter) and Congress' irritation at what it viewed to be a patronizing educational pamphlet published by OSHA on farm safety. The debate in the House was remarkable in its extreme hostility to the agency. For example, one congressman from a farm state, a sponsor of the rider, responded to an accusation that he wanted to "castrate OSHA" by saying, "Believe me, my colleagues, I do not want to castrate OSHA because if I do it might grow more rapidly. But if castration is the only solution I would sooner castrate the zealots who are drawing up regulations at OSHA than let them destroy the smaller farmers of America" (122 *Cong. Rec.* 20,366–20,372 [1976]). The other rider that was enacted that year eliminated OSHA authority to impose penalties on companies that are cited for fewer than 10 nonserious violations during an inspection.

Since 1976, five more riders have been added to the OSHA appropriations acts and, with minor changes, have remained in effect to the present. These riders relate for the most part to enforcement against small businesses; one deals with state plan monitoring; one with OSHA-Coast Guard jurisdiction; and another, demonstrating the legislative power of special small interest groups, limits OSHA enforcement in recreational hunting and fishing (Pub. L. no. 98–619, 98 Statutes at Large 3305).

The State Plan Framework and the Benchmarks Controversy

With the approval of the Virginia Plan in 1976, 23 states and one territory, the Virgin Islands, had received initial

approval of their plans. Eleven states that had originally submitted plans had withdrawn them by 1976; six of these (New Jersey, New York, Illinois, Wisconsin, Montana, and North Dakota) had already received OSHA approval when their plans were withdrawn. Five states had never submitted plans. Under the statutory scheme, a state first receives "initial" approval of its plan. After initial approval, federal OSHA has concurrent enforcement authority with the state. This concurrent jurisdiction was designed to ensure that workers in the state would continue to receive occupational safety and health protection during this transition period. This concurrent federal authority is discretionary, so that federal OSHA legally could discontinue its enforcement either in whole or in part at any time between initial and final approval. The transition period ends when the state's plan receives final approval, which is granted only after the state demonstrates in fact that implementation of its occupational safety and health program has been at least as effective as the federal program. After "final" approval, federal authority must end, unless formal proceedings are undertaken. However, because OSHA had decided to give initial approval to plans on the basis of promises to later meet their effectiveness goal (developmental plans), in 1972 OSHA committed itself not to exercise its discretionary authority to terminate federal enforcement during the developmental stage.

This commitment was reexamined and overridden by Assistant Secretary Stender in 1973, who expressed his special concern to avoid redundant state and federal enforcement. He decided to enter into operational agreements with states, thus ending federal enforcement. In order to achieve this sought-after operational status, a state was required to have in place legislation, standards that are at least as effective, a procedure to review enforcement actions, and sufficient number of enforcement personnel. This new policy drew strong criticism, not only from organized labor, which from the start had distrusted OSHA for what the unions believed was its abdication of federal enforcement responsibility to the states, but also from public interest groups and NACOSH. One of NACOSH's subcommittees issued a report objecting to the new policy and urging that federal enforcement continue until there had been evaluation by OSHA of the "in fact" effectiveness of the state plan *(Report of the NACOSH Subcomm. on State Programs)*. The NACOSH criticism elicited a strong negative response from Stender, who recommended that NACOSH abolish its subcommittees and concentrate on training and education issues. Congressman Steiger, whose relations with Assistant Secretary Stender were strained, said this step in restricting NACOSH's role would be a "tragic mistake." Stender's operational policy was carried out despite the opposition, and by the end of 1975 there were 13 operational agreements in effect (*The President's Report on Occupational Safety and Health*, 1975, p. 57).

Once a state has met all of its developmental requirements, it is certified by OSHA. After a period of further concentrated monitoring, the state plan is eligible for final approval, which can take place no sooner than one year after certification and three years after initial approval. The determination of whether a state in practice has been at least as effective, and therefore entitled to final approval, or deficient, and therefore subject to withdrawal proceedings, is based on OSHA's monitoring of the plan. OSHA's continuing monitoring of state plan effectiveness is required by Section 18 of the act and has included collection of statistical data, the examination of state case files, and investigation of complaints about state plan performance, known as CASPAs. On the basis of this monitoring, OSHA prepares reports with recommendations to the states for changes to improve effectiveness. Major problems with state plans in the past have been the lack of sufficient health enforcement personnel and lack of thoroughness in inspection activity.

By the end of 1976, five states had received certification: South Carolina, Iowa, Minnesota, North Carolina, and Utah. Fourteen states had operational status agreements (*The President's Report on Occupational Safety and Health*, 1976). However, it would be eight more years before OSHA would give final approval to a state plan. The primary reason for this was the benchmarks litigation, which began in 1974 and did not end until 1983.

The benchmarks litigation involved the validity of OSHA's numerical requirements for state compliance personnel under state plans. OSHA's interpretations of the "at least as effective" requirements were contained in the state plan regulations Part 1902, issued in 1972. Under OSHA's interpretation of the act, states were required to achieve staffs and budgets equal to those federal OSHA would have provided in that state in the absence of a state plan. Because of budget restrictions and resource limitations, it was conceded that the federal OSHA compliance staff was not as large as optimally needed. This meant that OSHA set state staffing requirements—or benchmarks, as they were called—at a relatively low level. Thus, a state could receive initial approval, certification, and final approval without providing—in the words of Section 18(c)(4) of the act, as understood by organized labor—"satisfactory assurances" that the state ultimately (at the end of the developmental period) would have "qualified personnel necessary for the enforcement" of the state program. The AFL–CIO challenged the OSHA interpretation, urging that state programs be required to provide adequate funds and staff "to ensure that normative standards are in fact enforced"; in other words, a judgment would be made as to whether the necessary staff had been hired by the state.

In 1978, the Court of Appeals for the District of Columbia decided *AFL–CIO v. Marshall*, 570 F.2d 1030. It rejected the notion that "at least as effective" means "at least as ineffective" and agreed with the AFL–CIO that personnel and funding benchmarks must be "part of a coherent program to realize a fully effective enforcement effort at some point in the foreseeable future." The Court remanded the case to OSHA for the establishment of criteria in accordance with

the decision. In 1980, Assistant Secretary Bingham submitted benchmarks substantially increasing the personnel requirements for the states. Particularly in the health area, these became the basis for continuing disagreement among OSHA, the states, and the AFL–CIO (U.S. Department of Labor news release, April 25, 1980).

Standards for Construction, Agriculture, and Other Industries

The Stender and Corn Administrations devoted much attention to dealing with criticism of the so-called nuisance safety standards adopted in 1971. Many of these were revoked in 1978; in addition, revisions of all other national consensus standards were undertaken, and a complete revision of subparts on fire protection and electrical hazards was issued in 1980 and 1981.

A number of safety standards projects were completed by OSHA between 1973 and 1976; some of these involved the construction industry. Whereas generally OSHA standards were vertical, applied across the board to all industries, in the construction and maritime industries OSHA's standards were horizontal, applying only to those industries. This special treatment was largely the result of historical reasons; OSHA's start-up standards in these areas were adopted as established federal standards from pre-OSHA statutes applying to these specific industries. Another unique feature of the construction industry's standards was OSHA's obligation to consult with the Construction Safety and Health Advisory Committee, which had been established under the Construction Safety Act to advise OSHA on standards for the construction industry. The construction committee was a standing committee, whereas most other standards advisory committees were ad hoc, meaning that OSHA had discretion as to whether to seek their advice on specific standards.

In 1972 OSHA issued a major addition to the construction standards that required rollover protection structures on construction equipment. Also in 1972, a subpart on power transmission and distribution lines was added to the construction standards. In 1976, OSHA required ground fault circuit interrupters (GFCIs) on electrical circuits in the construction industry.

Another industry that OSHA treated vertically was agriculture. The OSHA start-up standards contained only four limited standards applicable to agriculture. In 1972, the Migrant Legal Action Program and other groups petitioned OSHA to promulgate additional standards for agriculture. Shortly after the petition, in 1973, OSHA issued an ETS protecting farm workers from pesticide exposure. There was protest from Congress and from agricultural employers against OSHA's finding that pesticides create a "grave danger" to workers. The chairman of the Pesticide Subcommittee of OSHA's Agriculture Advisory Committee wrote to the assistant secretary that he was "shocked" by the action because there was "no disagreement" in the subcommittee "regarding the absence of any need" for emergency action (Arant–Stender letter, May 9, 1973). In 1974, the Court of Appeals for the Fifth Circuit vacated the standard, finding that the "easily curable and fleeting effects" of pesticide exposure on health did not meet the statutory requirements for a finding of "grave danger" (*Florida Peach Growers Association v. Department of Labor*, 489 F.2d 120 [5th Cir. 1974]). Although OSHA started rulemaking for a permanent pesticide standard to impose field reentry times for pesticide exposure, sharp disagreement arose with the EPA, which claimed jurisdiction over pesticide regulation under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). OSHA conceded to EPA authority, and ultimately, EPA jurisdiction was upheld by the Court of Appeals for the District of Columbia in a suit brought by a migrant worker public interest group against OSHA for abdicating its regulatory responsibility (*Organized Migrants in Community Action v. Brennan*, 520 F.2d 1161 [D.C. Cir. 1975]). OSHA issued two major agriculture standards, which were not challenged in court. The first, requiring rollover protection for agricultural tractors, was issued in 1975; the other, requiring guarding for farm equipment, was issued in early 1976.

Two other OSHA safety standards led to court decisions that were important in the evolution of the law governing OSHA standards. In partially vacating OSHA's action in reducing the number of lavatories required for office employees, the Court of Appeals for the Second Circuit faulted OSHA for the lack of substantial evidence and because of the inadequacy of the statement of reasons. The court said that when the public opposes a provision on "substantial" grounds, OSHA "has the burden of offering some reasoned explanation" (*Associated Industries v. Department of Labor* 487 F.2d 342 [2nd Cir. 1973]).

In *AFL–CIO v. Brennan* (530 F.2d 109 [3rd Cir. 1975]), the Court of Appeals for the Third Circuit followed the precedent of the asbestos case in upholding OSHA's elimination of the so-called no-hands-in-dies machines-guarding requirement. The court agreed with OSHA that the standard was not feasible as originally written and said that "an economically impossible standard would in all likelihood prove unenforceable, inducing employers faced with going out of business to evade rather than to comply with the regulation."

Health Standards: An Overview

A number of important actions on occupational health standards were taken by OSHA during this period, with a mixed record of success in the courts. Four emergency standards were promulgated—on vinyl chloride, pesticides, 14 carcinogens, and diving. Several were challenged, and all that were challenged were vacated or stayed by a court of appeals. OSHA issued four "permanent," or final, standards—on vinyl chloride, 14 carcinogens, diving, and coke oven emissions. These standards, issued after rulemaking, were affirmed in court of appeals decisions, except the standard for one of the carcinogenic substances, known as MOCA (4,4-methylene(bis)-2-chloroaniline), and one provision—medical surveillance in

the diving standard. Several rulemakings were begun but not completed until later; these included proposed revisions of OSHA standards on lead, hearing conservation, arsenic, and asbestos. A number of rulemakings were begun and abandoned; among them were those for trichloroethylene, beryllium, and sulfur dioxide (*The President's Report on Occupational Safety and Health*, 1975, pp. 22–23).

A number of general observations should be made regarding developments in health standards rulemaking and in court review of these proceedings.

ISSUES

All standards rulemaking, particularly on health standards, had become much more lengthy, complex, and controversial. (In the 1974 Annual Report for OSHA, 22 steps were listed in the standards development process [*The President's Report on Occupational Safety and Health*, 1974, pp. 9–11]). Two overriding issues were argued and resolved in standards proceedings: the PEL necessary to protect employees and the economic and technological feasibility of reaching that level through engineering controls. The question as to whether OSHA should require engineering controls as the primary method of achieving the permissible limit recurred in each proceeding. Although the details of the argument varied, the thrust of the business community's contention was that adequate protection from toxic substances could be achieved through the much less costly means of protective equipment. OSHA argued, and continues to maintain, that engineering controls are the preferred method of compliance, and that protective equipment should be used only when the preferred engineering controls were inadequate or not feasible. The basis for their argument is that protective equipment is unreliable because of the uncertainty as to whether it will be worn and whether it will afford complete protection.

Other issues relating to the nature of the protective equipment, medical surveillance, and monitoring and other requirements were often raised in standards proceedings. Affected parties uniformly presented witnesses who gave public testimony on the issues in the proceedings. Examination of witnesses, under the direction of the administrative law judge, routinely took place. At first OSHA allowed public comment but did not itself present witnesses or ask questions, but the agency soon found it necessary to offer expert witnesses and to question other witnesses to better defend the standard in court. Beginning with the vinyl chloride proceeding, OSHA contracted for feasibility studies, which became part of the record; often, as in the coke oven emissions and cotton dust proceedings, additional feasibility studies were introduced by employer associations. Presidential orders issued beginning with the administration of President Gerald Ford, who insisted on inflationary impact statements, required economic or regulatory analysis; more recently, President Reagan's Executive Order 12,291 required an agency to prepare a proposed and final regulatory impact analysis (RIA) for all "major" actions.

PREAMBLES

As the issues in the health standards proceedings became more complex, and the records more lengthy, the preambles to OSHA's proposed and final standards became considerably more detailed, each including a detailed analysis of the record, a summary of the contentions of the parties, and OSHA's resolution of each issue, with a section-by-section analysis discussing the basis of each provision and presenting preliminary interpretations of these provisions. Some recent standard preambles have been longer than 100 three-columned, printed pages in the *Federal Register*.

The significant trend toward very detailed statements of reasons was also made necessary by the increasing scrutiny that the courts of appeals were giving to OSHA's statements of reasons for the standards. The Court of Appeals for the Third Circuit, for example, vacated the challenged portion of OSHA's ETS on 14 carcinogens because of the inadequacy of the statement of reasons (*Dry Color Manufacturers Association v. Department of Labor*, 486 F.2d 98 [3rd Cir. 1973]).

REQUIREMENTS

The basic content of a health standard remained similar to the content of OSHA's first health standard, which was for asbestos. The key provision is the appropriate PEL, the level above which the employer is not permitted to expose employees. The PEL is usually expressed as an 8-hour TWA. Sometimes a ceiling, or short-term exposure level (STEL), is added; the issue of whether to include a more protective STEL has been critical in the recent ethylene oxide proceeding. An action level, usually one-half the PEL, is also often included in the standard, and is defined as the point where certain provisions of the standard, such as medical surveillance, are mandated. Other requirements (such as medical surveillance, monitoring, training, and record keeping) continued to be included, with refinements and elaborations reflecting agency experience and knowledge. In the area of medical surveillance, for example, OSHA evolved toward a statement of policy that employers were required to make medical examinations available to employees but that OSHA would not require that employees take the examination. (An employer could, of course, make the examination a condition of employment.) Questions on the type and frequency of monitoring and the extent and availability of employer records were often significant in the rulemaking proceedings, both during this period and continuing into the administration of Dr. Bingham. As will be discussed, the issues of mandatory transfer of employees who are at increased risk from exposure and wage retention became major issues after 1976.

PACE OF PROMULGATION

Because of resource limitations, and the increasing length of the proceedings, OSHA was falling farther and farther behind in its regulation of toxic substances. A variety of strategies were discussed and tried, with little noticeable impact. The so-called standards completion project to fill

out the bare-boned health standards adopted in 1971 was initiated by OSHA and NIOSH as a cooperative venture in 1975 but never completed. Later, during the administration of Dr. Bingham, the Carcinogens Policy was issued for the purpose of facilitating the issuance of standards on carcinogens; for a variety of reasons, the policy was never implemented. The OSHA policy for determining standards priorities was therefore extremely critical in its overall regulatory effort. Regulation of carcinogens was almost always OSHA's first priority, although other noncarcinogenic toxic substances that have serious health effects and are pervasively present in workplaces were also regulated. Examples of the latter efforts were the cotton dust and lead standards. Court suits requiring OSHA to rearrange its priorities and to initiate rulemaking were undertaken, usually by unions or public interest groups. The field sanitation suit in 1973 is an example; later, suits were brought to require OSHA to start rulemaking on ethylene oxide and formaldehyde. By 1987, court involvement in decisions on OSHA standards priorities were a regular feature of standards activity.

COURT PRECEDENTS

The courts of appeals, with only one exception, followed the lead of the Court of Appeals for the District of Columbia in the asbestos case, generally deferring to OSHA's policy judgments so long as they were within the bounds of rationality, particularly when the agency was acting to afford greater protection for workers. Thus, in the vinyl chloride case, the Court of Appeals for the Second Circuit upheld OSHA's one-part-per-million PEL. Even though the Court said "the factual finger points, [but] it does not conclude," it decided that "under the command of OSHA, it remains the duty of the Secretary to act to protect the working man, and to act even in circumstances where existing methodology or research is deficient." In that case, and in other standards review cases, the court upheld OSHA's policy judgment that evidence of carcinogenicity from animal studies should be extrapolated "from mouse to man." The court also applied the doctrine of "technology forcing" in *Vinyl Chloride*, in deciding that despite lack of substantial evidence establishing the technological feasibility of the one-part-per-million PEL, the standard was feasible because employers "simply need more faith in their own technological potentialities" (*Society of Plastics Industry, Inc. v. OSHA*, 509 F.2d 1301 [2nd Cir.], *cert. denied sub nom. Firestone Plastics Co. v. Department of Labor*, 421 U.S. 992 [1975]). On the other hand, in the Court of Appeals for the Fifth Circuit, the view was evolving toward closer scrutiny of OSHA's actions; this appeared first in that court's decisions on the pesticide and diving emergency standards and was proclaimed fully in 1978 when the court set aside OSHA's benzene standard, disagreeing with the deferential view of other courts of appeals (*American Petroleum Inst. v. OSHA*, 581 F.2d 493 [5th Cir. 1978]). This decision was later upheld by the Supreme Court, but on somewhat more narrow grounds.

PROCEDURAL SCRUTINY

Although they gave the agency substantial deference on policy judgments, the courts nevertheless insisted on rigorous adherence to the procedural requirements on rulemaking as stated in the OSHAct and the Administrative Procedure Act. As the court of appeals later said in the cotton dust case, the courts' role in the partnership is to ensure that the regulations resulted from a process of reasoned decision making, including "notice to the interested parties of issues presented in the proposed rule, opportunities for these parties to offer contrary evidence and arguments," and assurance that the agency has "explicated" the basis for its decision (*AFL–CIO v. Marshall* 617 F.2d 636 [D.C. Cir. 1979]). A number of OSHA standards, particularly during the early years, were vacated because of procedural defects.

EMERGENCY STANDARDS

Throughout OSHA's history, the courts of appeals applied particularly rigorous scrutiny to ETSs. The view was expressed by the Court of Appeals for the Fifth Circuit in the *Pesticides* case as follows: "Extraordinary power is delivered to the Secretary under the emergency provisions of the Occupational Safety and Health Act. That power should be delicately exercised, and only in those emergency situations which require it" (*Florida Peach Growers Association v. Department of Labor*, 489 F.2d 120 [5th Cir. 1974]). Other courts agreed with the Fifth Circuit Court of Appeals, at least on principle; for example, the Third Circuit, in *Dry Color Manufacturers Association v. Department of Labor*, 486 F.2d 98 (3rd Cir. 1973). Although it is clear that some emergency standards, such as the carcinogens standards, were vacated because OSHA had failed to follow proper procedures, increasingly, there were questions on whether any challenged emergency standard could be upheld, particularly after the Fifth Circuit Court of Appeals vacated OSHA's second asbestos emergency standard (*Asbestos Information Association v. OSHA*, 727 F.2d 415 [5th Cir. 1984]). Indeed, throughout the history of OSHA, only in one case, that of *Acrylonitrile*, when the judicial challenge was withdrawn after the court of appeals refused a stay of the standard (Visitron v. OSHA, 6 OSHC 1483 [6th Cir. 1978]), did OSHA prevail in court in a proceeding on an emergency standard.

Health Standards Proceedings

In March 1974, OSHA issued an ETS on vinyl chloride based on recently discovered evidence, both in animal studies and in humans, that the substance causes an unusual form of liver cancer. The ETS was preceded by a brief fact-finding hearing held by the agency, though this was not required by law. The emergency standard was not challenged and, after rulemaking, a permanent standard was issued in October 1974, six months after the ETS, which is within the statutory period. After a stay that lasted for a brief period, the court of appeals affirmed the standard and dissolved the stay. The Supreme Court refused to hear the case. This pro-

ceeding was generally recognized as successful both in terms of result and of speed in achieving protection for employees from a life-threatening hazard. In the words of Dr. Irving Selikoff, the regulation was "a success for science in having defined the problem; success for labor in rapid mobilization of concern; success for government in urgently collecting data, evaluating it, and translating it into necessary regulations; and success for industry in preparing the necessary engineering controls to minimize or eliminate the hazard" (OTA, 1985, pp. 230–231).

Some other OSHA health standard proceedings were not quite as successful. The regulation of field reentry time for pesticides, which has already been discussed, did not result in any OSHA regulation. The OSHA emergency standard on 14 carcinogens was set aside in part; after rulemaking, OSHA issued 14 permanent standards. The Court of Appeals for the Third Circuit vacated the standard for one of the carcinogens, MOCA, for procedural reasons: The court held that OSHA had failed to use the proper sequence of procedures in obtaining the recommendation of an advisory committee. The court upheld the standard as it applied to another carcinogen, ethyleneimine, deferring to OSHA's policy judgments on the interpretation of scientific evidence, and no challenge was filed as to the standards for other substances. OSHA has not issued another standard on MOCA (*Synthetic Organic Chemical Manufacturers Association v. Brennan*, 503 F.2d 1155; 506 F.2d 385 [3rd Cir. 1974]).

In 1977, OSHA completed rulemaking on the permanent diving standard, and on challenge from the Diving Contractors Association the Court of Appeals for the Fifth Circuit set aside the medical surveillance provisions. The court held that a portion of the medical requirements was beyond the agency's authority because the purpose was to protect the jobs of workers rather than to protect their occupational safety and health (*Taylor Diving & Salvage Co. v. Department of Labor*, 599 F.2d 622 [5th Cir. 1979]).

The widely praised coke oven emission proceeding was completed during Dr. Corn's term. The United Steelworkers of America petitioned OSHA for rulemaking based on strong epidemiological evidence demonstrating that coke oven emissions were carcinogenic. A standards advisory committee was formed in November 1974, under the chairmanship of Dr. Eula Bingham, who later became assistant secretary. (Dr. Bingham's statements favoring medical removal protection at a coke oven advisory committee meeting became an issue in the lead standard court proceeding in 1980, which will be discussed later in this chapter.) Based on the advisory committee's recommendations, but differing substantially from them, OSHA issued a proposed coke oven emissions standard in July 1975. After a comment period and a public hearing, OSHA issued a final standard in October 1976. The standard regulated the benzene-soluble fraction of total particulate matter present during the coking process, establishing a PEL of 150 $\mu g/m^3$. It also specified the engineering controls required; most health standards are different in this respect, mandating only a level and permitting the employer to select the specific controls. The standard was upheld by the Court of Appeals of the Third Circuit against an industry challenge; the court found the PEL necessary for the protection of employees and economically and technologically feasible. The court also upheld OSHA's authority to prescribe specific engineering controls (*American Iron and Steel Institute v. OSHA*, 577 F.2d 825 [3rd Cir. 1978]). Industry appealed the case to the Supreme Court, and although the Court agreed to hear the appeal, the petition was withdrawn before decision, and the court of appeals ruling thus became final.

Federal Safety: Trends in Injury Rates

In an effort to strengthen the federal agency safety and health program, Executive Order 11,807 was issued, effective September 28, 1974, superseding the order that had been issued in 1971. At the end of 1974, OSHA published guideline regulations implementing the new executive order and specifying the responsibilities of the federal agencies and OSHA's Office of Federal Agency Safety Programs (29 *CFR* 1960). The order was based on section 19 of the act, which requires the head of each federal agency, after consulting with employee representatives, to establish and maintain an effective and comprehensive occupational safety and health program consistent with the standards promulgated by OSHA for the private sector.

The underlying premise of the Federal Agency Program was that employees of the federal government need and are also entitled to protection. In addition, federal efforts to require private sector compliance would be severely hampered if the government were shown to have failed to provide a model by keeping its own house in order. However, despite the good intentions, criticism of the federal government's effort continued. In March 1973, the GAO published a report showing the need for improvements in the Federal Agency Program (GAO Report, March 15, 1973). In 1975, hearings were held in Charleston, SC, dealing with the U.S. Navy Shipyard and in Washington DC, with testimony received from various government executive departments, unions, and the GAO (*Safety in the Federal Workplace: Hearings Before a Subcomm. of the House Comm. on Government Operations*, 94th Cong., 1st Sess. [1975]). The Committee on Government Operations' report, entitled "Safety in the Federal Workplace," was issued in 1976 (H.R. rep. No. 94–784 [1976]). The report was sharply critical of the federal effort, pointing to the fact that agency policy directives were "vague and ambiguous," that "deficiencies" existed in consultation with employee representatives, and that the Department of Labor was "not staffed to perform the evaluations" of agency programs mandated by the law. The report noted that agencies had made commitments to improve their programs, but that because of "bureaucratic infighting," little progress had been made in meeting these commitments. The committee made numerous recommendations, including a suggestion

that OSHA accelerate its efforts to improve the accident and illness reporting system for federal employees. Congressional hearings and committee reports criticizing the federal government's internal safety and health effort have been a recurring component of the federal government program.

Meanwhile, the BLS continued to make its annual surveys of injuries and illnesses in the private sector. Based on reports submitted by private employers in 1976, the 1975 statistical survey showed that the overall incidence rate (the number of injuries and illnesses per 100 full-time workers) dropped from 10.4 in 1974 to 9.1 in 1975; however, OSHA said that the reduction could be explained due to the disproportionate decline in manufacturing and contract construction employment from 1974–1975. Despite the improvements, on the average, 1 out of every 11 workers experienced a job-related injury or illness, and the report itself again recognized the deficiency of the illness statistics. Four out of every 10 recorded illnesses were for skin diseases or disorders (*The President's Report on Occupational Safety and Health*, Dec. 1976, pp. 86–105). The decline in incidence rates did not continue, which lead to renewed and bitter controversy over the effectiveness of the OSHA program.

1977–1981: GIVING TEETH TO THE TIGER

A New Assistant Secretary

At an oversight hearing on OSHA held early in the Bingham Administration, Senator Harrison A. Williams, chairman of the Senate Labor Committee, observed that although OSHA originally enjoyed "broad support among legislators and the public," it was now perceived either as a "meddling, mischievous intrusion by the Government into the affairs of our Nation's businesses" or by others as a "paper tiger" (*Oversight on the Administration of the OSHAct: 1978 Hearings Before the Subcomm. on Labor of the Senate Comm. on Human Resources*, 95th Cong., 2nd Sess. [1978]). Jimmy Carter, elected president in 1976, gave high priority to improving the deteriorated image of OSHA. He selected Ray Marshall, a labor economist and professor, as secretary of labor and Dr. Eula Bingham, professor of toxicology at the University of Cincinnati, as assistant secretary. Dr. Bingham was no stranger either to occupational safety and health or to OSHA; she had served in 1973 as a member of the Carcinogens Advisory Committee and in 1974 as chairperson of the Coke Oven Emissions Advisory Committee. The new assistant secretary sought to give teeth to the OSHA tiger and, at the same time, to eliminate the agency as an irritant to business; her basic policy was a "shift to common-sense priorities." The reorganization of the national office staff, begun in 1976 and designed to improve coordination of field activity and to improve the agency's technical support activities, was fully implemented. The executive staff of the agency was almost completely changed. Dr. Bingham remained assistant secretary during President Carter's entire term of office. This was the longest administration in the history of OSHA. During this four-year period, there were numerous major shifts in OSHA policy and new initiatives. However, it is by no means clear that in 1981 OSHA enjoyed wider support than at the start of the administration.

Health Standards: The New Priority

From the start, Dr. Bingham emphasized the importance of standards activity, particularly standards regulating health hazards. In April 1977, soon after she came to office, Dr. Bingham told a subcommittee of the House Committee on Government Operations, "Quite honestly, I plan to stretch the resources of the agency in putting out health standards, and I intend to use the ETS authority whenever employees are exposed to grave danger." She added, "All I can say is watch the *Federal Register*" (*Performance of the OSH Administration: Hearings Before the Subcomm. on Manpower and Housing of the House Comm. on Government Operations*, 95th Cong., 1st Sess., 1977, pp. 77–78, 92).

Dr. Bingham's first standards effort was to lower the PEL for benzene, and although it was ultimately unsuccessful in terms of practical protective results, to many, the benzene proceeding was a turning point in the history of OSHA standards rulemaking.

One of OSHA's start-up standards regulated benzene exposure; the standard established a permissible level of 10 parts per million (ppm). More epidemiological evidence demonstrating that benzene causes leukemia had become available, and soon after reaching office, Dr. Bingham's attention was directed to the pressing need for increased protection to workers from benzene hazards. On April 29, 1977, Dr. Bingham signed an ETS lowering the PEL of benzene to 1 ppm, with a ceiling level of 5 ppm.

Both the Industrial Union Department of the AFL–CIO (IUD) and the American Petroleum Institute (API) filed petitions to review the emergency standard. Courts of appeals are divided into separate circuits, and both the IUD and the API sought review in a court that each thought would be favorable to its view, the IUD in the District of Columbia Circuit and API in the Fifth Circuit. A federal statute provides that when petitions are filed in different circuits, the court of appeals that decides the case is the one in which the first petition for review is filed. As a result, interested parties rush to file the first petition, in order to win what has been called the "race to the courthouse." The "race," at best, is unseemly and wasteful; in the case of benzene, the litigation was particularly complex because factual and legal disputes made it difficult to determine which was the first-filed petition. The litigation over the venue of the benzene appeal lasted for five months, during which time the standard was stayed, and therefore not in effect. In September 1977, the Court of Appeals for the District of Columbia issued a decision transferring the proceeding to the Court of Appeals for the Fifth Circuit. Although the judges agreed that the case should be transferred, they disagreed on the theory, and three separate opinions were writ-

ten, each presenting a different legal approach. In any event, because an emergency standard remains in effect no longer than six months, OSHA decided that it was not worthwhile to pursue the litigation any farther, and the ETS expired without ever being effective. The agency decided instead to concentrate its efforts on a permanent standard (*Industrial Union Department v. Bingham*, 570 F.2d 965 [D.C. Cir. 1977]).

After full rulemaking OSHA issued a permanent benzene standard, modifying the PEL to 1 ppm as a TWA, and a 5-ppm ceiling. There were no animal data on the carcinogenic effect of benzene, and the human data were at exposure levels considerably higher than the prior PEL of 10 ppm. In its preamble to the final benzene standard, OSHA asserted that the conclusions to be derived from the available data were that higher exposures to a toxic substance carry a greater risk, and because a determination of the precise level of benzene that presents no hazard cannot be made, the question of whether there is a safe level "cannot be answered" on the basis of present knowledge. Prudent health policy, the agency said, requires that the limit be set at the "lowest feasible level," which was found to be 1 ppm (43 *FR* 5918 [1978]). Thus, the lowest-feasible-level policy for carcinogens, as it was called, was the culmination of the regulatory theory, first expressed by OSHA in regulating asbestos, to resolve all doubts in favor of workers' protection.

The permanent standard was challenged primarily by the API in the Court of Appeals for the Fifth Circuit, this time without any race to the courthouse. The standard was immediately stayed, and in October 1978 the Court of Appeals vacated the standard on two grounds:

- The agency had failed to provide an estimate, supported by substantial evidence, of the expected benefits from reducing the PEL.
- OSHA did not assess the reasonableness of the relationship between expected costs and benefits.

In more familiar terminology, the court of appeals decided that OSHA must do a cost-benefit analysis. The court's decision was noteworthy because it departed markedly from the decisions of other courts of appeals, which gave great deference to OSHA decisions on health standards. The Fifth Circuit, however, defined its partnership with OSHA in a completely different way, insisting that OSHA "regulate on the basis of more knowledge and fewer assumptions" (*American Petroleum Institute v. OSHA*, 581 F.2d [5th Cir. 1978]).

Both OSHA and the IUD sought review, and the Supreme Court agreed to hear the case. On July 2, 1980, in one of the major regulatory decisions of the decade, the Supreme Court, in a sharply divided vote, invalidated the benzene standard. The lengthy written opinions of the justices of the Supreme Court, including those concurring on the results but disagreeing on rationale, are almost as significant as the decision itself. There was no majority opinion. The plurality—four justices—ruled that the act addresses only "significant risks" and does not seek to provide a "risk free" workplace; and that in developing standards, OSHA has the burden of showing by substantial evidence that it is addressing a "significant risk" of harm in the workplace, and that the proposed standard would eliminate or reduce that significant risk. Because OSHA had not met that burden (indeed, not knowing of the requirement, it had not even tried to do so), the benzene standard was vacated. The practical impact of the decision was that in the future, OSHA would have to establish the extent of risk from the toxic substance, even of carcinogens, quantitatively—usually by means of quantitative risk assessments—and then find that the risk was "significant." The OSHA "lowest-feasible-level" policy for carcinogens was rejected outright by the Supreme Court, and quantitative risk assessments are now a routine part of OSHA health standards development.

Because the Supreme Court had decided the case on other grounds, it did not have to consider the cost-benefit issue, leaving it for the next case. Both the plurality and the dissenting opinions were sharply worded and partly ideological in their thrust. For example, Justice John Paul Stevens, who wrote the plurality opinion, asserted that it would be "unreasonable to assume that Congress intended to give the Secretary the unprecedented power over industry that would result from the Government's view"; he refused to agree with OSHA that the "mere possibility that some employee somewhere in the country may confront some risk" as a basis for the secretary's requiring "the expenditure of hundreds of millions of dollars to minimize that risk." The dissent written by Justice Marshall was equally strident, accusing the majority of deciding the case not on the basis of congressional intent but rather "in line with the plurality's own view of proper regulatory policy" (*Industrial Union Department v. American Petroleum Institute*, 448 U.S. 607 [1980]). OSHA did not issue a new proposal on benzene until December 1985.

The cost-benefit issue was not resolved by the Supreme Court until the cotton dust proceeding. A proposed cotton dust standard had been published at the end of December 1976, shortly before Dr. Corn left. The rulemaking was completed, and after a major controversy with economists in the White House, who exerted pressure for a less costly final standard, Dr. Bingham issued the standard in June 1978 with only minor changes to accommodate the economists' view. The standard established a PEL of 200 $\mu g/m^3$ for yarn manufacturing and cotton washing, 750 $\mu g/m^3$ for slashing and weaving in the textile industry, and 500 $\mu g/m^3$ for textile mill waste house operations or for exposure to dust from "lower grade washed cotton" in yarn manufacturing. Rejecting industry arguments during the rulemaking, OSHA refused to perform a cost-benefit analysis, saying that prior attempts to quantify benefits as an aid to decision making had not proven "fruitful"; it based the PEL in the textile industry on an excellent epidemiological study performed by Dr. James Merchant and found that the standard was technologically and economically feasible. The Court of Appeals for the District of Columbia Circuit affirmed the standard

for the most part, rejecting the argument that the OSHAct requires cost-benefit analysis. The court said, "Especially where a policy aims to protect the health and lives of thousands of people, the difficulties in comparing widely dispersed benefits with more concentrated and calculable costs may overwhelm the advantages of such analysis" (*AFL v. Marshall*, 617 F.2d 636 [D.C. Cir. 1979]).

Industry appealed to the Supreme Court, and it withdrew its appeal to the Supreme Court in the coke oven emissions case, apparently so that the Supreme Court could direct its full attention to the cotton dust case. By this time, cost-benefit had emerged as the major OSHA regulatory issue. On the one hand, industry argued that cost-benefit would provide a "potential legislative check on what might otherwise amount to the exercise of virtually untrammeled authority" and allow the "correction, through the political process, of actions that are deemed by the Congress to be extreme, unwarranted, and inconsistent with congressional intent" (Brief, *American Textile Manufacturers Institute in American Textile Manufacturers' Institute v. Donovan*, 452 U.S. 490 [1981]). To other sectors of the public, unions and public interest groups, in particular, cost-benefit analysis was an anathema because it "places a monetary value on human life, thereby obliterating the moral purpose which led Congress to pass the OSHAct." (Comments of the United Steelworkers of America on the Advance Notice of Proposed Rulemaking for Cotton Dust, Docket No. 052B, May 29, 1981). The Supreme Court in June 1981 agreed with OSHA and the unions, and upheld the cotton dust standard as it applied to the textile industry. Relying in particular on the fact that neither the act nor the legislative history mentions cost-benefit analysis, the Court held that the act did not require that it be used. In his majority opinion, Justice William Brennan looked to the legislative history and concluded that Congress viewed the costs of safety as a cost of doing business. He quoted Senator Yarborough's statement, which was still relevant to the OSHA program: "We are talking about people's lives, not the indifference of some cost accountants" (*American Textile Manufacturers Institute v. Donovan*, 452 U.S. 490 [1981]). The Supreme Court opinion addressed only the issue in the case: whether the act requires cost-benefit analysis. The decision was generally understood to mean that cost-benefit was prohibited. The Supreme Court, however, opened the regulatory door somewhat, saying that "cost-effectiveness" analysis could be used; that is, once the agency decided what level of protection was necessary, it could adopt the least expensive means to achieve that level. As we shall see, cost-effectiveness analysis in the 1980s became one of the keystones in OSHA standards development.

Dr. Bingham issued two other emergency standards during the first years of her administration:

- The first, in September 1977, was for 1,2-dibromo-3-chloropropane (DBCP); this was based on findings that the substance was a carcinogen and caused sterility, and therefore created a "grave danger." The standard was not challenged and was replaced by a permanent standard in March 1978.
- In January 1978, OSHA issued another ETS, this time for acrylonitrile, also a carcinogen. The standard was challenged in the Court of Appeals for the Sixth Circuit, but the court refused a stay, and the court challenge was withdrawn. The ETS was superseded by a permanent standard in November 1978, which was not challenged.

Although Dr. Bingham had urged Congress to watch the *Federal Register* for emergency standards, none were published by her after January 1978. Indeed, in 1980, OSHA asserted a different policy approach. It said that there might be other occasions when the "level of the Agency's resources including compliance, legal and technical personnel, at a given time, may suggest that employee health may be more effectively protected by concentrating those resources in work on permanent standards" (Carcinogens Policy, 45 FR 5002, 5215–5216 [1980]). Undoubtedly, this judgment was also predicated on the legal vulnerability of emergency standards.

That statement was made in OSHA's carcinogens policy, issued in 1980. Its purpose was to provide a framework for the regulation of carcinogens in a "timely and efficient manner." The carcinogens policy contained policy determinations on the issues in the regulation of carcinogens that could be questioned only in specified circumstances in later substance-specific rulemaking proceedings. This, the agency said, was to avoid reargument of the same policy issues in each rulemaking proceeding. Although the lengthy preamble to the carcinogens policy was an important contribution to the principles of identification, classification, and regulation of occupational carcinogens, mainly because of the change of administration, the policy was never used and never resulted in the promulgation of a carcinogen standard; crucial portions of the policy were stayed by the agency in 1981. Thus, the considerable resources expended on the promulgation of the policy have failed at least for the present to achieve the saving of resources, for which it was designed.

Several other health standards were issued during Dr. Bingham's administration. An arsenic standard was issued in May 1978, lowering the PEL for the carcinogenic substance to 10 $\mu g/m^3$. In 1985, after reconsideration by the agency in light of the intervening Supreme Court decisions in the benzene case and the reaffirmation of the original PEL, the standard was affirmed by the Court of Appeals for the Ninth Circuit (*ASARCO v. OSHA*, 746 F.2d 483, [9th Cir. 1984]).

Another major proceeding was OSHA's regulation of lead hazards. Although not an occupational carcinogen, lead exposure affects numerous employees and industries and had long been known to result in serious illness. A proposed revised lead standard was issued in November 1975, during the Corn Administration; it proposed reducing the PEL for lead from 200 $\mu g/m^3$ to 100 $\mu g/m^3$. A final lead standard was issued in November 1978 by Dr. Bingham, further reducing the PEL to 50 $\mu g/m^3$, requiring the use of engi-

neering controls but affording affected industries periods of up to 10 years to comply with these requirements. The standard also contained a novel provision requiring employers to transfer employees who were at excess risk from lead exposure to lower-exposure jobs, and to maintain their wage levels and seniority generally for a period of up to 18 months while the employees were on the other jobs or laid off. This program came to be known as medical removal protection (MRP). It was designed to protect employees by encouraging participation in the medical surveillance program; the MRP provision had not been a subject of the original proposal, and a reopened hearing on MRP was held before the issuance of the final standard.

The standard was challenged in the court of appeals by the Steelworkers Union and the Lead Industries Association (LIA); two petitions for review were filed simultaneously in two different circuit courts of appeal. After a preliminary round of litigation on venue, the case was transferred to the Court of Appeals for the District of Columbia Circuit. In a lengthy opinion in August 1980, the court, with a vigorous dissent by Judge McKinnon on some issues, rejected numerous procedural challenges raised by LIA, based on lack of adequate notice by OSHA on the permissible level, *ex parte* communications, and bias of Dr. Bingham in prejudging the issue of MRP. The court found that substantial evidence supported the new PEL and that it was feasible for the major industries affected. The court also interpreted OSHA's authority expansively and ruled that it could require wage guarantees under the MRP provision. However, the court directed the agency to determine the feasibility of engineering controls for 38 other industries. The Supreme Court refused certiorari (*United Steelworkers v. Marshall*, 647 F.2d 1189, [D.C. Cir. 1980] *cert. denied* 453, U.S. 913 [1981]).

On the last day of her term, Dr. Bingham issued another final health standard regulating occupational noise. The original proposal had been issued in 1974 by Mr. Stender; after numerous studies and reopenings of the record, OSHA decided on January 16, 1980, to retain the 90-decibel level, to be achieved by engineering controls, but to require a hearing conservation program for employees exposed above 85 decibels. Mr. Auchter later suspended the standard and modified it, and extended litigation ensued. The Court of Appeals for the Fourth Circuit, *en banc*, upheld the standard in 1985. This litigation will be discussed later in this chapter.

Deletion of De Minimis Standards

One of the major accomplishments of the Bingham Administration was the deletion of approximately 600 safety standards in November 1978 (Revocation of Selected General Industry Safety and Health Standards, 43 *FR* 49, 726–49, 727, 1978). These standards were determined by OSHA to be unsuitable for regulatory purposes for a variety of reasons such as that they were obsolete, inconsequential, or directed to public safety. The broad review of OSHA national consensus standards promulgated in 1971 began in 1977, and two complete subparts were revised and simplified: the fire protection standards in 1980 and the electrical standards in 1981. In addition to eliminating provisions unrelated to worker safety and health, lengthy provisions of the reference materials were removed and placed in nonmandatory appendices. OSHA emphasized the "performance" approach, that is, giving employers the flexibility of selecting from among a variety of methods to provide the required protection. A standard regulating commercial diving operations was issued in 1977. A provision on medical surveillance in the standard was vacated by the Court of Appeals for the Fifth Circuit (*Taylor Diving and Salvage Co. v. Department of Labor*, 599 F.2d 622 [5th Cir. 1979]), and OSHA's enforcement of the diving standard was largely superseded when the Coast Guard issued a parallel standard in 1978. Two other safety standards were issued during the Bingham Administration:

- A standard on servicing of multipiece wheel rims.
- A standard on the guarding of low-pitched roof perimeters. This was issued in response to a series of unfavorable court decisions on the issue of whether OSHA's perimeter guarding standard covered roofs (see, for example, *Diamond Roofing Co., Inc. v. OSHRC*, 528 F.2d 645 [5th Cir. 1976]).

"Common-Sense" Enforcement Policy

The OSHA program of "common-sense priorities" was intended to focus workplace inspections on health hazards, larger workplaces, and the more serious health hazards. From fiscal year 1976 to 1977, the percentage of total inspections that were health inspections rose from 8.4 percent to 15.2 percent, and then to 18.6 percent and 19.2 percent in 1978 and 1979. The focus on health hazards was demonstrated by the continuing growth of the industrial hygiene staff. In 1976, OSHA had 967 safety inspectors and 314 industrial hygienists, but by the end of 1980, there were 972 safety inspectors and 548 hygienists. A critical aspect of Dr. Bingham's common-sense priorities was her emphasis on serious hazards. Under the program, 95 percent of OSHA's programmed inspections targeted the industries with the most serious health and safety hazards; the determination of hazards was based on the annual BLS survey. Similar targeting was initiated for health hazards, but the lack of adequate illness data limited the effectiveness of this targeting. Finally, OSHA directed that the field compliance officers spend the bulk of their time on actual inspection activity, with only 30 percent of their time permitted for support work. The National Emphasis Program continued to be implemented at least through 1977, but new crises brought forth new emphases. A series of grain elevator explosions at the end of 1977, leading to more than 50 employee deaths, resulted in OSHA's targeting that industry for inspection activity and initiating a review of standards in the industry (*The President's Report on Occupational Safety and Health*, 1977). The new OSHA targeting resulted in an increase in inspections in the more hazardous manufacturing sector (43.7 percent in

fiscal year 1976, 52.1 percent in fiscal 1977, and 52.3 percent in fiscal 1978). The percentage of inspections in the hazardous construction sector also grew, but more slowly, rising from 25.9 percent in fiscal 1977 to 45.5 percent in fiscal 1981. By 1983, the construction percentage had grown even more, to 58.1 percent. The percentage of inspections in other industries continued to drop as the number in the targeted industries increased.

During this period OSHA continued to give priority to inspections in response to employee complaints; however, a major change was made in 1979 on the issue of informal complaints. Because a great proportion of OSHA inspection resources was being expended on inspecting in response to nonwritten, sometimes nonemployee, complaints, many of which did not result in the discovery of workplace hazards, OSHA revised its Kepone-inspired policy and decided that inspections would be conducted in response to informal complaints only when they appeared to involve imminent dangers or extremely serious hazards. Otherwise, OSHA said, it would send a letter to the employer, advising him or her of the complaint "and of the action required." If the employer response was satisfactory, no inspection would be conducted; if unsatisfactory, or no response was received, an inspection would be conducted. In addition, as a check, random inspections would be conducted in the case of every 10th informal complaint. As a result of this change, the percentage of complaint inspections dropped significantly, from a high of 37.6 percent in 1978 to 23.4 percent in fiscal 1981. This made possible substantial increases in the numbers of targeted inspections, which, of course, was the major goal of the new policy. The issue of response to employee complaints again became a major issue—this time legislative—in 1980 with the introduction of the Schweiker bill, as will be discussed in the section relating to OSHA and Congress.

During Dr. Bingham's administration, OSHA also embarked on a serious effort to give added credibility to the sanctions imposed for violations disclosed during workplace inspections. In the past, no sanctions were imposed for nonserious violations (largely because of congressional action in appropriations riders), and even when fines were imposed for more serious hazards, they were rarely high enough to constitute a deterrence to future violation. The charge that OSHA was a "paper tiger" was based in major part on the lack of meaningful sanctions. Under Dr. Bingham, the amounts of proposed penalties for serious, willful, repeated, and failure-to-abate violations all rose sharply. For example, in fiscal 1977, the proposed penalties for serious violations were approximately $6 million; in fiscal 1980, they were just over $11.3 million. In February 1980, OSHA proposed a record penalty (up until then, the record had been $786,190) against Newport News Shipbuilding and Dry Dock Company for 551 alleged safety and 66 alleged health violations. A major factor in the increase in total penalties was the parallel increases in the percentages of serious and willful violations being cited. Increased emphasis was also placed by OSHA on sending criminal cases to the U.S. Justice Department. Under the OSHAct, criminal penalties can be imposed for willful violations of a standard causing the death of an employee. Instructions emphasizing the importance of the criminal sanctions were sent to field staff, and in 1980, for example, nine cases were referred to the Justice Department for possible criminal action, bringing the total since OSHA began to 27 referrals (*The President's Report on Occupational Safety and Health*, 1980). However, there were few convictions in these cases, and the effectiveness of the criminal provisions have been seriously questioned.

Not surprisingly, this more vigorous enforcement brought with it a sharp rise in both the rate and the number of contests. In fiscal 1973, the rate of contest was 2.7 percent, with 1,315 cases being contested; in fiscal 1980 the rate was 11.7 percent, and there were 7,391 contested cases. This meant that the backlog of cases for decision by the Review Commission, which had always been a problem, increased at an alarming rate. In addition, regional solicitors (the attorneys for OSHA) found it increasingly difficult to handle the greater litigation load, particularly because many of the administrative proceedings were complex and time-consuming, involving expert testimony on the feasibility of engineering controls. Attempts by regional solicitors to settle cases with reduced penalties and sometimes by reducing the nature of the violation were often criticized by unions that were parties to the proceedings and even by OSHA officials. Increasing tension between lawyers and clients resulted until 1980, when Dr. Bingham issued a directive to field staff authorizing area directors themselves to adjust citations and penalties before the contest period. This informal settlement policy had the desired effect, and the contest rate dropped sharply in fiscal 1981 to 6.3 percent. The policy was well received and particularly attractive to the next OSHA administration of Auchter, which gave added emphasis to the policy, leading to an even greater reduction in the contest rate, to 1.9 percent in fiscal 1983.

A major legal development affecting enforcement activity during the Bingham Administration was the Supreme Court decision that Fourth Amendment protection against unreasonable search and seizure applied to OSHA inspections. OSHA argued that Congress had intended prompt and unannounced inspections and that a warrant requirement would delay entry to the workplace, defeat the legislative purpose, and "significantly impede the implementation of OSHA." The Supreme Court, in *Marshall v. Barlow's Inc.*, 436 U.S. 307 (1978) (decided in May 1978) rejected OSHA's arguments, saying that it was unconvinced that the warrant requirement would impose "serious burdens on the inspection system or the courts." In the first place, the Supreme Court said, the "great majority" of businessmen could be expected to consent to inspection. Furthermore, "probable cause in the criminal law sense is not required." According to the Court, OSHA could obtain the warrant by showing that the establishment was selected on an "adminis-

trative plan for the enforcement of the Act derived from neutral sources"; the Court referred specifically to OSHA's targeting plan, which was based on accident experience and dispersal of employees. Finally, the Court said, there was no reason why OSHA could not change its regulations to authorize its obtaining *ex parte* warrants; that is, without first notifying the employer or holding a hearing before the district court. Since *Barlow's*, about 3 percent of OSHA inspections have resulted in warrant proceedings.

OSHA had consistently emphasized that the "compliance assistance" aspects of its program (education, consultation, and informational assistance) were an integral part of the total OSHA program. In April 1978, OSHA launched its "New Directions" grants program. Its purpose was to use labor unions, trade associations, educational institutions, and nonprofit organizations to provide job safety and health education and training to employers and employees, including assistance in hazard recognition and control and training in employer and worker rights. The amounts funded by OSHA in the New Directions program increased during the Bingham Administration, and in August 1980, OSHA awarded $3.5 million to 66 organizations for training and education in hazard abatement. This was in addition to 82 continuing grants re-funded at $13.4 million (*The President's Report on Occupational Safety and Health*, 1980). In 1980 oversight hearings before the Senate Labor Committee, Deputy Assistant Secretary Basil Whiting testified on three "success stories" of the New Directions program: health and safety seminars for high-level foundry management sponsored by the Pennsylvania Foundrymen's Association; formal instruction in safety and health to employees of a large electronics manufacturing company by Indiana University; resolution of a problem causing job illnesses by the Machinists Union, in cooperation with management. At the same oversight hearing, Mr. Whiting testified on the continued expansion of the on-site consultation program. He noted that employer demand for those services had grown and that in 1979 one out of every six OSHA-related visits to worksites was a consultative visit and not an inspection (*Oversight on the Administration of the Occupational Safety and Health Act: Hearings Before the Senate Comm. on Labor and Human Resources*, 96th Cong., 2nd Sess. 24 [1980] [referred to hereafter as *Oversight Hearings*, 1980]).

Increasing Worker Participation

Secretary Ray Marshall said in 1980, "During its first 7 years, the Agency dealt almost exclusively" with the rights of the employer "with little attention to the role of the workers in recognition and abatement of hazards." This, he said, had been remedied by the Bingham Administration, which concentrated equally on the contributions "all parties can make" (*Oversight Hearings*, 1980, pp. 1034–1044). One of OSHA's first steps in this direction was the revision of instructions in the FOM in 1978 to assure employees and to encourage employee participation in the opening, closing, and informal conferences, "when practical." If it was not practical to hold a joint conference with employers and employees, the instructions required separate conferences to be held (Program Directive No. 200-82, Aug. 15, 1978). The issue of the payment of employee wages for walkaround time reemerged at the start of Dr. Bingham's term of office. Early in the history of OSHA, a legal determination was made that employees were not entitled to pay for walkaround time. One of Dr. Bingham's first actions in 1977 was to reverse that decision; the solicitor of labor issued a new interpretation that the employer's refusal to pay for walkaround was discrimination (because the exercise was a protected right) and therefore illegal. The U.S. Chamber of Commerce challenged this interpretation, and in 1980 the Court of Appeals for the District of Columbia upset the walkaround pay rule on the grounds that it had been issued by OSHA without OSHA first having gone through public notice and comment proceedings. Sharply criticizing OSHA for its "high handed" action and for treating the procedural obligations as "meaningless ritual," Judge Tamm noted for the court that public comment serves the practical purposes of reducing the risk of factual errors, arbitrary actions, and unforeseen detrimental actions (*Chamber of Commerce of the United States v. OSHA*, 636 F.2d 464 [D.C. Cir. 1980]). OSHA immediately started notice-and-comment rulemaking in January 1981, shortly before the end of Dr. Bingham's administration. The 1981 regulation was short-lived, however. On assuming office, Assistant Secretary Auchter delayed the effective date of the rule, and, following a period of public comment, revoked it. At present, there is no legal requirement on walkaround pay, although such pay is required by some collective bargaining agreements.

A particularly troublesome issue was employee participation in commission and court litigation. Although the OSHAct expressly states that workers have a right "to participate as parties to hearings," major disagreements arose on the role of employee parties with respect to the withdrawal of a citation and penalty by OSHA, and employees' right to participate in the settlement of contested citations and penalties. Employee groups argued that they have the right to object to withdrawals and prejudicial settlements, which derives from their statutory right to participate as parties in commission proceedings. They argued further that it is essential that they—for whose protection the law was passed—have the right to prevent OSHA's lawyers from reducing or eliminating citations and penalties for reasons often unrelated to worker participation, such as resource limitations.

The solicitor of labor argued, on the other hand, that it has "prosecutorial discretion" to decide not only whether to issue citations but also whether to prosecute them or settle them. The controversy became particularly sensitive because the OSHA view was being advanced by its lawyers, who were committed to the view that they should control litigation, even though OSHA as agency did not uniformly side with its attorneys on the issue. Attempts to settle the controversy by

providing for informal consultation between unions and the solicitor's office were not successful, and the issue was litigated through the commission and the courts. In 1985 the Supreme Court sided with the solicitor, giving the agency exclusive control over withdrawal and settlement of citations (*Cuyahoga Valley Ry. Co. v. United Transportation Union*, 106 S. Ct. 286 [1985]). Nonetheless, the courts have held that employees have the right to appeal adverse commission decisions to the court of appeals, even if OSHA does not wish to pursue the case (*Oil, Chemical & Atomic Workers International Union v. OSHRC [American Cyanamid*], 671 F.2d 643 [D.C. Cir. 1982], *cert. denied* sub nom. *American Cyanamid Co. v. OCAW*, 456 U.S. 969 [1982]).

Section 11(c) of the act, like analogous provisions in other regulatory statutes, protects employees against reprisal in the exercise of their statutory rights. One section-11(c) case, *Whirlpool Corp. v. Marshall*, reached the Supreme Court. It involved the question of whether employees have the right to refuse to work under conditions that are reasonably believed to be imminently dangerous. The Supreme Court unanimously held that the secretary's regulation affirming this right was valid, saying that the regulation "on its face appears to further the overriding purpose of the Act, and rationally to complement its remedial scheme" (445 U.S. 1 [1980]). The *Whirlpool* case involved a safety hazard—the fall from potentially dangerous heights. The application of the refusal-to-work principle to health hazards, with long latency periods, is less clear and has not been definitively resolved. The issue is analogous to the question of whether health hazards would constitute imminent dangers. This, too, has not been resolved; indeed, throughout the history of OSHA, the number of imminent danger proceedings, either safety or health, has been extremely limited. It is not entirely clear that, as has sometimes been claimed, voluntary action by employers in apparent imminent danger situations has prevented the need for employees to resort to court proceedings.

Criticism of OSHA's implementation of the section 11(c) program has continued. One of the major issues has been the delays in the processing of employee section-11(c) complaints by OSHA. Another is the delays in cases reaching trial, even if OSHA decides to prosecute the case. In 1980, a representative of the Oil, Chemical and Atomic Workers International Union told a Senate committee "without exaggeration" that section 11(c) "no longer works" (*Oversight Hearings*, 1980, pp. 873–879). To help remedy the situation, an attempt was made to imply the right of individual employees to sue an employer under section 11(c), at least when OSHA refuses to act, but the Court of Appeals for the Sixth Circuit in 1980 decided that the act means what it says: that only the Secretary of Labor can sue in court to vindicate section-11(c) rights (*Taylor v. Brighton*, 616 F.2d 256 [6th Cir. 1980]).

The right of employees to know of conditions in the workplace was addressed in the act and amplified considerably during the administration of Dr. Bingham. Under the statute, an employer who is cited must post the citation prominently "at or near" the place where the violation occurred. Also, under the mandates of sections 6(b)(7) and 8(b)(3), all OSHA substance-specific health standards include provisions requiring labels or other forms of warning on toxic substances, access of employees to their medical records, and provisions requiring that employees have an opportunity to observe workplace monitoring and have access to monitoring records. In July 1978, OSHA amended its record-keeping regulations, originally issued in 1971, to give employees, former employees, and their representatives access to the employer's injury and illness log and to the summary of recorded occupational injuries and illnesses (29 *CFR* 1904.7[b]).

In 1980, another major step in employees' right to know occurred, with the issuance of a regulation providing for employee access to the employer's existing monitoring and medical records. The new rule did not mandate the creation of new records; it applied only to those that employers had already developed under the employer's own ongoing programs. However, the new rule applied to records relating to a broad range of toxic substances—not just to the limited number of substances that OSHA had regulated with specific health standards. In 1982, a federal district court upheld the access rule in all respects, rejecting, among others, arguments based on employer trade secret rights and employee rights of privacy. In May 1984, the Court of Appeals for the Fifth Circuit summarily affirmed the rule without opinion (*Louisiana Chemical Association v. Bingham*, II OSHC 1922 [5th Cir. 1984]).

Probably the most important area of employees' right to know addressed by OSHA was hazard communication. The agency's involvement with requirements for employer identification and communication of hazards in the workplace began almost at the beginning of the program. An advisory committee recommended a standard in 1975, as did the National Institute for Occupational Safety and Health, and the House Government Operations Committee held a number of hearings aimed, at first unsuccessfully, at pressing OSHA to issue a hazard communication standard. Dr. Bingham published a proposed standard on hazards identification, as it was then called, just prior to the end of her administration. The standard would have required employers to assess the hazards in their workplace; and labels containing extensive information about hazards would have been required on all containers, including pipes. The proposal was withdrawn just after the beginning of Auchter's administration, as part of the regulatory reevaluation that was undertaken under Executive Order 12,291. As will be discussed, a significantly revised hazards communication standard was issued in 1983, and in 1985 it was largely upheld by the Court of Appeals for the Third Circuit.

Continuing Congressional Oversight

Many amendments have been proposed throughout the history of OSHA, almost all curtailing the agency's authority, but none has been passed. OSHA has invariably opposed

these weakening amendments, a position that has been generally supported by the labor committees of the two houses, which, as strong proponents of the OSHA program, have consistently refused to report out "anti-OSHA" bills. The pressure for amendment of the OSHAct has been significantly relieved through the device of appropriations riders limiting OSHA authority in various respects, which have functioned as a catharsis for congressional frustration with OSHA and opposition to certain of its policies.

The greatest legislative threat to OSHA was the bill introduced by Senator Richard Schweiker of Pennsylvania in 1979. The bill primarily would have completely revamped OSHA inspection priorities; it sought to reduce OSHA safety inspection activity in "safe" workplaces, "safe" being determined by establishment injury data for past years in that workplace. OSHA's targeting programs had been based on industry-wide rates rather than individual establishments' injury inspection rates. In introducing the bill, which would also have limited OSHA response to employee complaints—even those meeting formality requirements—in "safe" workplaces, Senator Schweiker said, "The bottom line is this: After 9 years under the Act's present safety regulatory scheme, we are left with no demonstrable record that it works and with a bad taste all around from the experience" (125 *Cong. Rec.* 37,135-37,137 [1979]).

Senator Schweiker's assertion that OSHA does not "work" seemed to be borne out by the statistical record of injuries. According to BLS surveys, beginning with 1976 and continuing to 1980, there were increases in both the lost workday case incidence rate and the lost workday incidence rate. In the 1975 survey, the case incidence rate per 100 full-time workers for lost workday cases was 3.3; four years later, it was 4.3. The incidence rate for lost workdays in 1975 was 56.1 and in 1979 it was 67.7. Although the incidence rate for cases without lost workdays went down somewhat during that period, the statistics did not establish the marked improvement in workplace safety that had been anticipated by the OSHAct's sponsors. Dr. Bingham and others countered by saying that statistics "provide only a partial picture of the true state of safety and health in the workplace" (U.S. Department of Labor news release, Nov. 20, 1980). The testimony of Lloyd McBride, president of the United Steelworkers of America, at the Senate oversight hearing also argued that the wider benefits of OSHA were not measurable through statistics (*Oversight Hearings*, 1980).

Assistant Secretary Bingham testified vigorously in opposition to the Schweiker bill on both practical and philosophical grounds. The targeting system would decrease protection, she said. "Is an air carrier not inspected for safety because it had no accidents the prior year?" she asked. Dr. Bingham also sharply criticized the bill for its change in complaint policy, which overturned OSHA's "fundamental policy judgment" that (*Hearings on X. 2153 Before the Senate Comm. on Labor and Human Resources*, 96th Cong., 2nd Sess. 33-36 [1980])

> *if an employee actually working in the facility and exposed on a daily basis to hazards cares about his safety and health sufficiently to write the Secretary of Labor about it, and is courageous enough to ask for direct help from OSHA by signing his name to the complaint, that employee deserves and should receive an on-site inspection if the complaint, in OSHA's judgment, appears to have merit.*

Organized labor joined OSHA's major effort to defeat the bill, which was never reported by the Senate Labor Committee. In 1979, Senator Schweiker introduced an appropriations rider that was enacted, which served a similar purpose, limiting OSHA inspections of "safe" employers with 10 or fewer workers. An appropriations rider does not require the approval of the agency's standing committee (for OSHA, the labor committees), thus avoiding a major stumbling block to passage. The Schweiker rider has remained in effect.

Simultaneous with its legislative hearings on the Schweiker bill, the Senate Labor Committee also held general oversight hearings on the administration of the OSHAct. As is usually the case in oversight hearings, testimony covering many topics related to the program was presented by representatives of a variety of interests: unions, employers' associations, academicians, state officials, professional organizations, public interest groups, and many others. Representatives of OSHA, the agency, typically also appear at oversight hearings; their testimony constitutes a report on the state of the agency, often anticipating issues of concern to the committee. Questioning by members of the committee, particularly of OSHA witnesses, is thorough and often sharp.

In 1979, for example, OSHA testified at six congressional hearings, including one held by the subcommittee on investigations of the House Post Office and Civil Service Committee held a hearing on the Federal Agency Program; a hearing was held by a subcommittee of the Home Labor and Education Committee on the effectiveness of the OSHA enforcement program in the Philadelphia area. In July, OSHA testified on the concerns of small businesses before the Judiciary Committee's Subcommittee on Administrative Practice and Procedure. The OSHA representatives also testified before three different subcommittees on cost-benefit analysis on the issue of extending OSHA coverage to legislative and executive employees and on OSHA enforcement of standards affecting migrant workers (*The President's Report on Occupational Safety and Health*, 1979). Tragedies causing multiple deaths of employees often lead to congressional oversight hearings to determine the cause of the accident and whether action is needed to avoid recurrences. Examples include the hearings after a series of grain elevator explosions that caused many employee deaths in December 1977 and January 1978, and the hearing held by a subcommittee of the House Labor and Education Committee in June 1978 in St. Mary's, West Virginia, following the Willow Island cooling tower collapse, which caused the death of 78 employees

(*OSHA Oversight—Willow Island, West Virginia Cooling Tower Collapse: Hearings Before the Subcomm. on Compensation, Health and Safety of the House Comm. on Education and Labor*, 95th Cong., 2nd Sess. [1978]).

The 1980 oversight hearing elicited wide interest, particularly because of the parallel legislative hearing. Many of the witnesses were prominent: Secretary of Labor Marshall appeared in addition to Dr. Bingham and Basil Whiting. Lane Kirkland, president of the AFL–CIO; Howard Samuel, president of the IUD; and Lloyd McBride, president of the United Steelworkers of America, testified for organized labor. (The witnesses representing business interests had appeared for the most part in the prior legislative hearings.) McBride's testimony was a broad-ranging evaluation of OSHA activity over the period of 10 years. He commented, "Probably the major impact of the first decade of OSHA has been the development of an occupational safety and health infrastructure, which, in turn, generates its own ameliorating influence upon the hard conditions of work and the workplace." He cited, among other things, safety and health clauses in bargaining agreements and the increase in the number of professionals in the area (*Oversight Hearings*, 1980, 698-699, 745-751). Of course, not all testimony was favorable to the agency; many groups and interests including organized labor criticized various facets of OSHA activity. Mike McKevitt, representing the National Federation of Independent Business, claimed that OSHA would continue to have little positive impact unless it gave up its "steadfast adherence" to specification standards. In sum, oversight and legislative activity, including consideration of proposed amendments and the appropriations process, have served as the major means for Congress's continuous monitoring of the administration of regulatory programs.

Interagency Cooperation and Controversy

OSHA continued to work closely with other federal agencies that had occupational safety and health responsibilities, but disputes continued and it was often necessary for parties to resort to litigation in order to settle jurisdictional issues. An example is *Northwest Airlines*, 8 OSHC 1982 (Review Comm. 1980), involving safety responsibility for maintenance work on airplanes, in which the Review Commission held that the Federal Aviation Administration had exercised authority and preempted OSHA. Some jurisdictional agreements were reached, notably with the Coast Guard in the Department of Transportation (45 *FR* 9142 [1980]) on jurisdiction over employees working on the outer continental shelf and the Mine Safety and Health Administration in the Department of Labor (44 *FR* 22, 827 [1979]). Dr. Bingham was particularly committed to the cooperative governmental efforts of the Interagency Regulatory Liaison Group (IRLG). Established in 1977, the IRLG consisted of five major social regulatory agencies: OSHA, the EPA, the Consumer Product Safety Commission, the Food and Drug Administration, and the Food Safety and Quality Service of the Department of Agriculture. Because these agencies have common regulatory responsibilities, their directors determined that it would be beneficial for them to share their research facilities' knowledge and personnel. The IRLG established seven work groups with the responsibility of developing consistent approaches among the agencies in such areas as compliance and enforcement, epidemiological activity, risk assessments, and testing standards (*The President's Report on Occupational Safety and Health*, 1978). One of the major products of IRLG activity was its publication of a major policy report on procedures for the determination of whether chemicals were carcinogenic and the extent of the risk. The report was prepared by the Risk Assessment Group of IRLG, with the assistance of scientists from the National Cancer Institute and the National Institute of Environmental Health Sciences, and was published in February 1979 (*The President's Report on Occupational Safety and Health*, 1979).

A New Executive Order

In February 1980, President Jimmy Carter signed Executive Order 12,196, adding many new features to the Federal Employee Safety and Health Program (45 FR 45,235 [1980]). Among the provisions in the order, which greatly strengthened the program, federal agency heads are required to comply with OSHA standards applicable to the private sector unless the secretary of labor approves compliance with alternative standards. For the first time, OSHA was given authority to conduct on-site inspections of federal agency facilities in specified circumstances and to recommend abatement measures. Agency heads were authorized to establish safety and health committees comprising an equal number of management and employee representatives. Such a committee, by majority vote, can request an OSHA inspection if it is not satisfied with the agency response to a report of hazardous working conditions. The order duplicated OSHA's policy on private employers in prohibiting discrimination against employees for the exercise of protected rights and providing for employee walkaround rights. The order also authorizes "official time" for employees participating in activities under the order. A substantial revision of the Department of Labor's regulations, newly entitled "Basic Program Elements for Federal Employee Occupational Safety and Health Programs," that reflected the new executive order was also issued by OSHA in 1980 (29 *CFR* 1960).

The Bingham Administration Ends

Dr. Bingham's administration ended as it began—with a flurry of activity. During the last several weeks, a number of standards and regulations were issued, on walkaround pay, hearing conservation, hazard communication, and several other items of somewhat less major consequence involving supplemental decisions in lead and the carcinogens policy. Not all were destined to be long-lived, but the assistant secretary's commitment to vigorous standards and enforcement action continued to the last day of her term of office.

1981 TO 1987: OSHA'S BALANCED APPROACH

The election of Ronald Reagan in 1980 inaugurated a new era in the history of OSHA. President Reagan appointed Ray Donovan as secretary of labor and Thorne Auchter as assistant secretary for OSHA. Auchter, who had been a construction executive, served as assistant secretary from March 1981 to March 1984. After Auchter's resignation, Roberts Rowland, a Texas attorney who was previously chairman of the Occupational Safety and Health Review Commission, served as assistant secretary under a recess appointment for about nine months. Rowland's term was controversial, and he resigned in mid-1985, soon after William Brock became secretary of labor. Patrick Tyson, a former attorney in the Office of the Solicitor, headed OSHA in the absence of an assistant secretary until early 1986. John Pendergrass, a certified industrial hygienist, took office on May 22, 1986, and served as assistant secretary until March 31, 1989. Assistant Secretary Auchter summarized his approach to OSHA to a subcommittee of the House Labor Committee in 1982:

> *Only by working together can business, labor and government achieve their common goal of safe and healthful workplaces. The varied authorities granted under the Act allow a wide range of agency activities and programs that involve the government and the private sector in cooperative efforts. We have accordingly developed a balanced program mix that focuses not only on standards-setting and enforcement, but also on ways of helping employers and employees solve safety and health problems in the workplace.*

He listed as examples of "self-help approaches" on-site consultation, education, and training, and other voluntary protection methods (*OSHA Oversight—Agency Report by Assistant Secretary of Labor for OSHA: Hearings Before the Subcomm. on Health Safety of the House Comm. on Education and Labor*, 97th Cong., 2nd Sess. 2–4 [1982]).

A New Era in Compliance

Consistent with his philosophy of "working together," Auchter instituted a number of changes in enforcement priorities and procedures. In the past, follow-up inspections (that is, OSHA reinspections of establishments under a commission order to abate hazards to determine if abatement in fact had taken place) were more or less routine. This policy was revised by Assistant Secretary Auchter; he stated that because experience showed that almost all firms visited in follow-up inspections were in compliance, the agency was deemphasizing follow-ups, keeping them to an "essential minimum." This would permit OSHA inspection resources to be focused in higher-priority areas. Sharp reductions in the number of follow-up inspections took place: In fiscal year 1980, follow-ups were 18.4 percent of all inspections; in 1981, 9.5 percent; and in 1982, 2.5 percent. In fiscal year 1986, 3 percent of OSHA inspections were follow-ups (16 *OSHR* 911, 1987). Also noting the high contest rate, Auchter underscored the existing policy of informal conferences between OSHA regional staff and employers, so that, "whenever possible," settlement agreements under which the employer agrees to comply would be reached. As anticipated, the result was, in Auchter's words, a "dramatic drop" in contested cases: from 25 percent of all OSHA inspections in fiscal 1980 to approximately 8 percent in fiscal 1981 and 2.8 percent in 1982. In fiscal 1986, the contest rate was 3.6 percent (16 *OSHR* 912, 1987). OSHA also issued guidelines on the use of the general duty clause to avoid its unwarranted use. In early 1982, one of Auchter's earliest actions was to withdraw the walkaround pay regulation after notice and comment.

Another innovation by OSHA was to target high-hazard establishments in the manufacturing sector for inspections. Under the new procedures, applicable to programmed inspections for general industry in the safety area, compliance officers continued to visit establishments based on the high-hazard industry list. At the beginning of the inspection, however, the compliance officer would inspect the firm's lost workday injury rate (the number of lost workdays per 100 workers). If the particular firm's rate was below the most recently published national lost workday rate for manufacturing, the inspector would not walk through the workplace and conduct a full-scale safety inspection. The purpose of this system, according to Auchter, was to identify and inspect "only those workplaces where there is a high likelihood of finding serious problems." The program did not apply to health inspections, nor did it affect OSHA's response to complaints. In fiscal 1983 there were 71,303 inspections and 8,444 records inspections—a new category, inspections of records and not of workplaces. In fiscal 1986, there were 64,071 inspections, of which 4,619 were records inspections (16 *OSHR* 911, 1987).

Responding to criticism that excluding companies with low lost workday injury rates from the threat of inspection eliminates the incentive for compliance, OSHA announced in 1986 that it was allocating 5 percent, or about 700, of its programmed safety inspections to manufacturing establishments with below-average lost workday rates. In addition, OSHA announced its intention to undertake a comprehensive inspection of every 10th high-hazard industry manufacturer that had undergone only a records review by the agency (15 *OSHR* 867, 1986).

The new, "balanced" approach of OSHA was viewed differently by all groups. Shortly after the program was instituted, the AFL–CIO stated that the system was "ill-conceived" and "unsound," removing numerous manufacturing employers from "one of OSHA's most effective compliance tools . . . the threat of general scheduled safety inspections" (*Oversight on the Administration of the Occupational Safety and Health Act: Joint Hearings Before the Subcomm. on Investigations and General Oversight and Subcomm. on Labor of the Subcomm. on Labor and Human Resources*, 97th Cong., 1st Sess. 171 [1981]).

OSHA has also continued to implement special-emphasis targeting programs in response to new information showing particular hazards to employees. The grain elevator inspection, in effect since 1977, was renewed. In August 1985, OSHA instituted a targeting program for the fireworks industry, after 30 employee deaths occurred in fireworks-manufacturing facilities (16 *OSHR* 133–134, 1986). Following the Bhopal, India, catastrophe, OSHA instituted a pilot Special Emphasis Inspection Effort in the chemical industry in 1985. Congress called for a report on the program, and on July 15, 1985, OSHA preliminarily noted instances disclosed in its inspections of chemical facilities where hazardous conditions were not addressed by OSHA standards (16 *OSHR* 147–148, 1986).

Consultation, education, and training were major components of the Auchter compliance effort. On-site consultation activity was emphasized and expanded. By 1985, 52 states and jurisdictions provided consultation services to employers. Under revised consultation regulations issued in 1984, an employer is given a one-year exemption from OSHA general-schedule inspection (but not complaint inspections or accident investigations) if it undergoes a comprehensive consultation visit, corrects all identified hazards, and demonstrates that it has an effective safety and health program in operation (49 *FR* 25, 082, 1984). The regulations also broadened the scope of consultation to include advice on the "effectiveness of the employer's total management system" to ensure safety and health at the workplace. In 1985, the program's first full year of operation, OSHA granted a total of 382 exemptions to participating employers (*The President's Report on Occupational Safety and Health*, 1985). In light of the diminished chance that an employer would receive an OSHA programmed inspection, however, some have questioned whether there is any great incentive for employers to participate in the consultation program (OTA, 1985).

Three new Voluntary Protection Programs—Star, Praise, and Try—were instituted in 1982. (The Praise Program has since been discontinued.) Each of the programs was directed at a different category of employers, but all were "based on the premise that [an employer] having a comprehensive safety and health program which operates effectively can provide a greater worker protection than the chance of an OSHA enforcement inspection." For employers accepted under one of these programs, OSHA programmed inspections are discontinued but complaint inspections and accident investigations are handled in accordance with regular procedures (*The President's Report on Occupational Safety and Health*, 1985, pp. 60–61). In early 1986, there were 26 general-industry and three construction employers in Star and six general-industry employers in Try. A construction company with injury rates nearly four times the injury average was removed from the Try Program in November 1985—the first time, according to OSHA, that an employer was removed (15 *OSHR* 845, 1985).

The New Directions grant program, which was designed to develop competence in nonprofit organizations for safety and health training and education for employers and employees, continued. Significant changes were made, however. The program funding was cut down substantially, from $13.9 million in fiscal year 1981 to $6.8 million in fiscal years 1982 and 1983, and $5.6 million in 1985 (OTA, 1985; *The President's Report on Occupational Safety and Health*, 1985). In 1981 OSHA stopped using a peer review process under which persons affiliated with grant recipients evaluated applicants for new grants. The reason given was that peer review was "too costly and resulted in a possible conflict of interest" because those who had received grants evaluated applicants (*How OSHA Controls and Monitors Its New Directions Program*, Draft report, GAO No. HRD, 85–29, p. 7 [1984]).

In 1983, OSHA made a major change in New Directions program requirements, making educational and other nonprofit organizations ineligible to receive grants unless they had previously been approved for a planning grant. Educational and other nonprofit organizations can be members of a consortium eligible for a grant, but there must be a labor or employer organization in the consortium that assumes responsibility for submitting the proposal and administering the grant (*The President's Report on Occupational Safety and Health*, 1985). The COSH groups (local safety and health coalitions) were no longer funded, and a 1986 report issued by the public interest group Public Citizen sharply criticized OSHA for eliminating its funding of these occupational safety and health coalitions.

In order to better focus the activity of New Direction grantees in high-priority areas, in November 1985 OSHA announced that in the future it would award grants only to organizations that proposed to develop education and training programs in one of four specific areas: chemical industry, chemical and toxic substances, hazardous waste sites, and new OSHA standards (Notice of Grant Program, 50 *FR* 47, 294 [1985]; *The President's Report on Occupational Safety and Health*, 1985).

The debate over the wisdom and success of OSHA's new orientation continued. In 1983 the Center for Responsive Law, a public interest group, published a report critical of the Auchter Administration, asserting that the terms v*oluntary, cooperative*, and *nonadversarial* are "clear code words for regulatory abdication." Much the same view was expressed in another public interest report, Retreat from Safety, issued in 1984. Auchter responded to the earlier report of the Center for Responsive Law, saying it was "flawed and biased," that it relied on "inaccurate and misleading statements, undocumented opinions, and unrepresentative anecdotes to support its preconceived conclusions" (13 *OSHR* 408, 1983). When the BLS injury statistics showed improvement during the early years of Auchter's administration, Auchter referred to this fact as demonstrating that the administration's new approach to enforcement had succeeded whereas the prior "tough" enforcement approaches had failed, as evidenced by the growing injury rate before 1981.

The States: A Partnership Once Again

Assistant Secretary Auchter also took a radically different approach to state programs. He said in 1981 that it was his "firm intention" to "resolve differences" that have existed in the past between the federal and state OSHAs and "to develop a management and policy framework that in the future will integrate the states into the overall OSHA program." In the last analysis, he said, "local problems are best addressed by those closest to them" (*State Implementation of Federal Standards: Hearings Before the Subcomm. on Intergovernmental Regulations of the Senate Comm. on Governmental Affairs*, 97th Cong., 1st Sess. 14–25 [1981]). Among the steps taken by Mr. Auchter to implement this partnership was to terminate the withdrawal proceedings against Indiana, deny the petition for withdrawal of the Virginia plan, and enter into operational agreements with the remaining states with approved plans, thus ending discretionary federal enforcement in those states. One of the major initiatives of the Auchter administration was to radically reverse Dr. Bingham's benchmarks, which Mr. Auchter viewed as the major impediment to final approval because of their "stringent requirement." OSHA supported a rider to its appropriations bill that would preclude the expenditure of agency funds to implement the court of appeals benchmarks decision; this was an unusual response, because the agency had traditionally opposed riders as a means of legislating. The rider was passed, but elicited opposition and resentment, and was deleted by Congress in December 1982, never to be renewed.

At this point, OSHA embarked a broad reconsideration of Bingham benchmarks. At the request of OSHA, a State Plan Task Group was established in August 1983 to work with OSHA in reviewing and revising the benchmarks. The task group decided that the original benchmark formula used in 1980 was "conceptually sound" but that modifications in input were necessary to incorporate, where available, state-specific data and "to build flexibility into the formula to accommodate differences among states" (Kentucky, Final Approval Notice, 50 *FR* 24,884, 24,886 [1985]). Twelve states completed revision of their benchmarks. During 1985, eight states (Arizona, Iowa, Kentucky, Maryland, Minnesota, Tennessee, Utah, and Wyoming) obtained approval of their revised benchmarks and final approval of their state plans, making 11 final approvals in all (*The President's Report on Occupational Safety and Health*, 1985). In January 1986, OSHA approved revised benchmarks for four more states (Indiana, North Carolina, South Carolina, and Virginia), and final approval was granted to the Indiana state plan in September 1986 (51 *FR* 34,215). The AFL–CIO voiced strong opposition to the new benchmarks because of the substantial reductions in the number of inspectors required for final approval. In the 12 states, for example, 171 health inspectors would make the states eligible, instead of 746, as in 1980. The unions argued that the decrease conflicted with the court of appeals decision and that the number of inspectors required failed to provide for, among other things, enforcement of new standards (15 *OSHR* 903–904, 1986). In commenting on the revised benchmarks, the United Steelworkers of America complained that the revision enabled each state to "manipulate" the number of workplaces to be covered by the inspection program in order to justify current staff levels (O'Brien, 1985, p. 1).

Assistant Secretary Auchter also changed OSHA's state monitoring system. Section 19(f) of the OSHAct requires OSHA to make a continuing evaluation of how the state is carrying out its approved plan, which would be the basis for determining whether the state should receive final approval. The main components of OSHA's monitoring system had been case file reviews, spot-check visits by federal inspectors of establishments previously inspected by state enforcement personnel, and accompanied visits by federal inspectors of actual state inspection and consultation visits. An appropriations rider in 1980 radically limited OSHA's spot-check monitoring authority; during that year, state representatives testified at House oversight hearings, strongly criticizing OSHA's monitoring activity.

Under Auchter's new monitoring system, first implemented in August 1983, there was a shift in emphasis in state plan evaluation from "intrusive on-site monitoring to analysis of the state-submitted statistical data" (*The President's Report on Occupational Safety and Health*, 1983, p. 41). The monitoring system compared state statistical information in 11 major program areas such as standards, variances, consultation, and enforcement to federal performance, also as statistically measured, although states were "not necessarily" expected to equal federal performance in respect to each measure. A primary component of the system was the identification and analysis of outliers, that is, "state performance on a particular performance measure that falls outside the established level or range of performance" required in comparison to the federal program (OSHA Instruction STP 2.22A "State Plan Policies and Procedures," 1986, Chapter 3). An outlier is not necessarily a deficiency but requires "further explanation." Most data used to evaluate state performance are obtained through state participation in the Integrated Management Information System (IMIS). As of 1986, 22 states were participating in IMIS. These states provide data to the system either by forms for OSHA entry or by direct entry using OSHA-provided equipment.

On July 1, 1987, the California state program covering private employers ceased operations when funding ended because of a budget dispute (17 *OSHR* 199, 1987).

Health Standards, Continued

Auchter early on directed his attention to OSHA's health standards activity. The administration's attempt to modify OSHA's historic position against cost-benefit analysis was rejected by the U.S. Supreme Court in the cotton dust case, which held that the act prohibited cost-benefit analysis. This was only the beginning; the health standards area continued

to be characterized by controversy, including some major litigation, throughout the Reagan Administration.

Among the major trends in standard development during this period were the following:

➢ In 1986, OSHA stated that its approach to standards encompassed the following elements:

Adopting "less rigid, performance-oriented standards."

Addressing "existing, significant risks" and adopting requirements that will "significantly" reduce such risks.

Adopting requirements that are technologically and economically feasible.

Using the most "cost-effective" approach (*The President's Report on Occupational Safety and Health*, 1985, pp. 7–8).

➢ In determining "significant risk" for health standards, OSHA typically would prepare one or more quantitative risk assessments, by means of which OSHA would quantify the excess risk from the disease for various PELs. Based on these numerical calculations, OSHA would determine whether the risk was significant under the benzene case guidelines.

➢ On February 17, 1981, President Reagan issued Executive Order 12,291 "to reduce the burdens of existing and future regulations, increase agency accountability for regulatory actions, provide for presidential oversight of the regulatory process, minimize duplication and conflict of regulations, and ensure well-reasoned regulations" (E.O. 12,291). Significant requirements of the order were the preparation by agencies of a preliminary and final Regulatory Impact Analysis (RIA) for each "major" regulatory action and the review of these analyses by officials in the OMB. As a result of Executive Order 12,219, the OMB was assigned a major role in reviewing OSHA standards activity. In several standards proceedings, OSHA standards actions were questioned and often delayed by OMB. In the ethylene oxide proceeding, the legality of OMB involvement was sharply challenged by the Public Citizen Group (a public interest group). As will be discussed, the court of appeals vacated OSHA's standard partly, but without considering the OMB question.

➢ In this period, OSHA undertook only limited new health standard actions, and in some cases it was pressured to do so by litigation. Two new final standards were issued, for asbestos and ethylene oxide, and several rulemaking proceedings are under way at this writing. At the same time, OSHA's attempts to significantly cut back the stringency of previously issued standards were mostly unsuccessful. A notable example is the revision of the cotton dust standard, which, although revised, was retained substantially as originally promulgated in 1979.

➢ Somewhat reluctantly, the courts of appeals have been thrust into deciding cases raising the question of whether OSHA should be ordered to commence rulemaking or complete previously delayed rulemaking. Two major decisions were issued by the Court of Appeals for the District of Columbia in this area. The first directed OSHA to promulgate an ethylene oxide proposal within 30 days. Ultimately, the agency issued a final standard, which was further challenged in the court of appeals. Early in 1987, the court of appeals sharply criticized OSHA for its 14-year delay in issuing a field sanitation standard, and directed that a final standard be promulgated within 30 days. The standard was issued in April 1987 (52 *FR* 16,050).

➢ OSHA's overall past success in defending its standards in court continued throughout this period. However, this success, as before, did not extend to the Court of Appeals for the Fifth Circuit, which in 1983 set aside OSHA's emergency standard on asbestos. OSHA issued no other emergency standard during the Reagan Administration.

➢ A major area of new litigation was the preemption of state standards activity; this arose particularly in connection with OSHA's hazard communication standard.

➢ OSHA sought to use "negotiated" rulemaking procedures in developing a revised benzene standard. This cooperative approach had earlier been attempted briefly and unsuccessfully with the coke ovens standard. Although negotiations ultimately failed in the benzene proceeding (OSHA later proposed its own revised standard), the negotiated approach later succeeded in developing a proposed standard for MDA (4,4'-methylene dianiline) (16 *OSHR* 1451, 1987). However, skepticism continued to be expressed about the usefulness, or even legality, of these efforts (15 *OSHR* 942, 1986).

➢ The assistant secretary and many others continued to express concern over OSHA's slow pace in standards development. Early in 1987, the Administrative Conference published a report noting "severe management problems" in OSHA's standards-setting process (16 *OSHR* 995, 1987). Congress made clear its concern about OSHA's promptness in issuing standards when it required in the Superfund Amendments and Reauthorization Act of 1986 (SARA) that OSHA issue a protective standard for hazardous waste site operations within 60 days of the date of enactment. The law was enacted on October 17, 1986; the OSHA interim standard, effective immediately, was published on December 19, 1986 (51 *FR* 45,654 [1986]).

The major individual OSHA rulemakings during the Reagan Administration were related to cotton dust, hearing conservation, hazard communication, asbestos, field sanitation, and ethylene oxide.

COTTON DUST

One of the requirements of Executive Order 12,291 pertained to regulations pending when the Order was issued in 1981. These had to be reviewed by the agency to determine their consistency with the policies of the new executive order. The cotton dust case, involving the issue of cost–benefit analysis, was then pending before the U.S. Supreme Court, briefs having been submitted and oral arguments held. In March 1981,

OSHA, through the solicitor general, filed a supplemental memorandum with the Supreme Court, asking the Court to refrain from deciding the case so that the agency would be able to "reconsider the cotton dust standard and the role of cost-benefit analysis under the Act" in light of the new order. The Supreme Court, in deciding the case and prohibiting cost-benefit analysis, rejected OSHA's request for a second chance in a footnote, without giving reasons. Although the Supreme Court thus affirmed the cotton dust standard as it applied to the textile industry, the agency proceeded with its reevaluation of the standard, publishing a notice of proposed revisions in June 1983. Prior to the issuance of the proposal, there was an extended dispute between OSHA and OMB over the scope of the reconsideration—particularly as to whether engineering controls should continue to be required—but in its proposal, OSHA ultimately adhered to its established policy of requiring engineering controls. Revisions in the cotton dust standard were eventually issued in December 1985, following, according to reports, another dispute between OSHA and OMB over the scope of the medical surveillance requirements in the standard. The revised standard, according to OSHA, contained substantial cost savings while maintaining health protection for workers (50 *FR* 51,120 [1985]). Two challenges to the cotton dust standard were rejected by the Court of Appeals for the District of Columbia in 1987.

HEARING CONSERVATION

The OSHA hearing conservation amendment, issued by Dr. Bingham in January 1981, was also significantly affected by the change of administration. Auchter quickly stayed the effective date of the amendment, and then stayed it a second time; there followed a suit by the AFL–CIO challenging the stays, because they were issued without notice and comment. In the meantime, Auchter issued an interim revised hearing conservation amendment in August 1981 and, after rulemaking, a final revised amendment in March 1983. A variety of changes were made in the Bingham standard, mostly emphasizing a more flexible "performance" approach. In other words, employers were given flexibility in complying, and compliance would therefore be encouraged "in the manner that is easiest under the circumstances present in the particular work environment" (48 *FR* 9738 [1983]).

The standard was challenged by an employer association, and in November 1984, in an unexpected and remarkable decision, the court of appeals, with one dissent, vacated the hearing conservation amendment on the ground that the agency failed to distinguish between hearing losses caused by workplace noise and those caused by nonworkplace noise, and therefore "clearly imposes responsibilities on employers based on nonwork-related hazards." This, the court said, was "not a problem that Congress delegated to OSHA to remedy." OSHA and the AFL–CIO moved for a hearing by the full court; the union emphasized the impact of the court's decision not only on the noise standard but on all other OSHA health standards in which it is often impossible to separate between workplace-related illness and illness caused outside the workplace. The full court reconsidered the case and in October 1985 reversed the original decision, completely rejecting its reasoning and finding the standard feasible and supported by substantial evidence (*Forging Industry v. Secretary*, 773 F.2d 1436 [4th Cir. 1985]).

HAZARD COMMUNICATION

The proposed hazard communication standard was also published at the end of Dr. Bingham's administration. The standard was quickly withdrawn by the new administration in February 1981 "for further consideration of regulatory alternatives," and in March 1982 a revised hazard communications proposal was published, limited to the manufacturing sector. The standard also "accommodated" the health interest and the economic interest in trade secret protection by "narrowly defining the circumstances under which specific chemical identity must be disclosed." It is significant that the standard was challenged only by a union (the United Steelworkers of America), a public interest group (Public Citizen), and by several states. Employers did not challenge the standard. Indeed, they generally supported a federal OSHA hazard communication standard; employers hoped its effect would be to preempt the "multiplicity of differing and conflicting State and local hazard communication laws" which "impose an undue burden on products moving in interstate commerce and on multistate employers" (Final Hazard Communication Standard, 48 *FR* 53,280 [1983]).

In May 1985, the Court of Appeals for the Third Circuit issued an important decision, ruling in the favor of the challenging parties on several critical issues. First, the court ruled that OSHA had failed to adequately justify its limitation of the hazard communication requirements to the manufacturing sector, thus ignoring the recorded evidence that workers in sectors outside of manufacturing are also exposed to toxic materials hazards. Secondly, the court found that OSHA afforded unduly broad trade secret protection. Suggesting that a rule that protected only "formula and process information but [required] disclosure of hazardous ingredients" would adequately protect trade secrets, the court of appeals directed OSHA to reconsider this issue as well as the scope of the standard. Finally, the Court rejected OSHA's limitation of access to certain confidential information to health professionals (*United Steelworkers of America v. Auchter*, 763 F.2d 728 [3rd Cir. 1985]).

On September 30, 1986, OSHA issued a final rule amending the hazard communication standard to provide wider access to trade secrets in nonemergency situations, and to eliminate trade secret protection for chemical information that can be discovered readily through reverse engineering processes (51 *FR* 34,590 [1986]). However, OSHA delayed issuing even a proposal on extending the scope of the hazard communication standard for more than 18 months and the court of appeals issued a second decision ordering OSHA to broaden the standard within 60 days, or to explain why it

was not feasible to do so (*United Steelworkers v. Pendergrass*, 13 OSGC 1305 [3rd Cir. 1987]).

In the meantime, in October 1985, the Court of Appeals for the Third Circuit decided another case involving New Jersey's Right-to-Know Law (New Jersey does not have an OSHA state plan). A variety of business groups claimed that the New Jersey law was preempted by the OSHA hazard communication rule. Under the OSHAct, the laws and regulations relating to occupational safety and health in states without approved OSHA plans are preempted as to issues covered by the federal OSHA program. The court made two distinctions: between the manufacturing and nonmanufacturing sectors and between workplace and environmental hazards. It decided that the New Jersey law was preempted by the OSHA standard only in respect to the identification and disclosure of workplace hazardous substances in the manufacturing area—that is, on the "issue" that was covered by OSHA's standard. There was no preemption on nonmanufacturing activities, the court held, because the OSHA standard did not apply to those activities. Finally, the court ruled that there were unresolved factual questions about whether there was preemption as to state labeling requirements for environmental hazards (*New Jersey State Chamber of Commerce v. Hughey*, 774 F.2d 587 [3rd Cir. 1985]).

In September 1986, courts of appeals handed down two additional decisions further outlining the complex rules on the effect of the hazard communication standard in preempting state and municipal requirements. The first related to the Pennsylvania Right-to-Know Ordinance (*Manufacturers Association of Tri-County v. Krepper*, 801 F.2d 130 [3rd Cir. 1986]; *Ohio Manufacturers' Association v. City of Akron*, 801 F.2d 824 [6th Cir. 1986]). (Note: Effective May 4, 1988, all employees were required to follow the rules of the hazard communication standard.)

ASBESTOS

Assistant Secretary Auchter took a major regulatory action in November 1983, issuing an ETS lowering the PEL for asbestos to 0.5 fibers per cubic centimeter of air. The existing PEL was 2 fibers per cubic centimeter, which was established in 1976 at the expiration of the four-year delayed effective date of OSHA's first asbestos standard, issued in 1972. In 1975, meanwhile, OSHA proposed a 0.5 PEL for asbestos, but no further action had been taken on the proposal. In 1983, OSHA performed a risk assessment and concluded that for all workers exposed to 0.5 fibers per cubic centimeter, there would be an estimated 196 excess cancer deaths per 1,000 workers with 45 years of exposure, 139 deaths for those with 20 years, 10 for one year, and 6 extra deaths per 1,000 workers with six months of exposure. On the basis of these statistics, OSHA said, "The overall extraordinary degree of risk, the extent that very high risk is found in many asbestos using industries, and the unusually high quality of the data utilized to make these assessments present a very strong evidentiary basis for a 'grave danger' finding" (ETS on Asbestos, 48 *FR* 51,086 [1983]). The ETS was quickly challenged by a trade association representing 47 employers and by a number of individual employers. On November 23, the Court of Appeals for the Fifth Circuit granted the stay, and in March 1984 held that the standard was invalid.

The decision of the court of appeals was significant not only because it vacated a particular ETS, but because of its negative implications for any OSHA emergency standards, at least in the Fifth Circuit. This standard, unlike some earlier ones that were vacated, would have regulated a substance that is known to cause death and serious physical harm; OSHA had performed extensive and careful risk assessments, statistically demonstrating the excess risk at various levels of asbestos exposure, and the preamble set forth the agency data, its reasoning, and findings in detail. Yet the court of appeals, once again warning that the emergency authority must be "delicately exercised," faulted OSHA for its mistake in calculating the number of deaths that could be avoided over a six-month period—"substantially less than 80," the court said—and held that "evidence based on risk assessment analysis is precisely the type of data that may be more uncritically accepted after public scrutiny, through notice-and-comment rulemaking especially when the conclusions it suggests are controversial or subject to different interpretations" (*Asbestos Information Association v. OSHA*, 727 F.2d 415 [5th Cir. 1984]).

After rulemaking, including a public hearing that lasted from June 19 to July 10, 1984, and a printed record of 55,000 pages on June 20, 1986, OSHA issued two final standards regulating exposure to asbestos and related materials; one standard applied to general industry (including maritime) and the second to the construction industry. The standards lowered the PEL for asbestos to 0.2 fibers per cubic centimeter (OSHA's 1972 standard was 12 fibers per cubic centimeter). The requirements of the construction standard were tailored to the unique characteristics of the industry—notably, the fact that construction industry worksites are nonfixed and are temporary in nature (Final Asbestos Standard, 51 *FR* 22,612 [1986] [to be codified at 29 *CFR* 1910.1001]). Challenges to the new asbestos standard were filed quickly. Two departments of the AFL–CIO sought review, claiming that OSHA's regulation was not stringent enough. The Asbestos Information Association, an employer organization, sought review because it had "questions about the feasibility, particularly of monitoring, at the new Permissible Exposure Limit." Petitions for review were also filed by R. T. Vanderbilt and the National Stone Association, challenging OSHA's regulation of nonasbestiform tremolite, actinolite, and anthophyllite. In July 1986, OSHA stayed the standard insofar as it applied to these substances, pending reconsideration. The review proceedings were all transferred to the Court of Appeals for the District of Columbia (16 *OSHR* 885 1986).

FIELD SANITATION

Throughout the history of OSHA, courts have been petitioned to review standards already issued by OSHA. However, more recently the courts have been pressed into another role, that of deciding suits brought to compel OSHA (or other regulatory agencies) to initiate rulemaking actions for the issuance of a standard, or to issue standards when the completion of rulemaking is unduly delayed. In a period when OSHA standards development, in the view of many groups, has slowed down, it is not surprising that this type of proceeding has become more common.

The courts' authority to review standards that have been issued is explicitly granted in the OSHAct. It is less clear whether a court can or should decide whether a standards proceeding should be initiated. A decision to undertake rulemaking typically involves the weighing of competing demands for agency resources; the importance of a variety of projects; and considerations of general policy, priorities, and politics. In such situations, the court obviously has preferred to give the agency great discretion in determining what actions to take. Also, in a suit to compel agency action, there is typically no record before the court on the basis of which a decision could reasonably be made. Despite these strong considerations against review, courts on occasion have found the agency actions so arbitrary as to justify a finding of abuse of agency discretion, and have directed that action be taken. As an alternative, the court may require the agency to make a decision—whether to publish a proposal or not—without determining the particular action that should be undertaken.

The field sanitation proceeding raised the issue of OSHA's failure to promulgate standards requiring toilet and drinking facilities for agricultural workers parallel to the sanitation requirements for nonagricultural workers that it imposed in 1971. A suit was brought in December 1974 by the Migrant Legal Action Program to require OSHA to initiate rulemaking. First OSHA published a proposed standard, but angry congressional pressure forced it to drop the rulemaking. The case reached the Court of Appeals for the District of Columbia for the first time in 1977. The court was willing to give broad deference to OSHA's discretion on rulemaking priorities, saying, "With its broader perspective, and access to a broad range of undertakings, and not merely the program before the Court, the agency has a better capacity than the Court to make the comparative judgments involved in determining priorities and allocating resources." However, the court of appeals insisted that OSHA, which had never said that a field sanitation standard should not be issued, develop a timetable indicating when it would be in a position to complete rulemaking (*National Congress of Hispanic American Citizens [El congreso] v. Usery*, 554 F.2d 1196 [D.C. Cir. 1977]). The agency developed timetables and on several occasions in 1981 said that it could not work on field sanitation for the next two years because of higher priorities, and that it would be between 58 and 63 months before the standard would be issued. The district judge, who had been sympathetic to the suit of the migrant workers from the outset, rejected the timetable, saying that the existence of other OSHA work doesn't justify "relegating a simple Standard of Field Sanitation to the dust bin" (*National Congress of Hispanic American Citizens v. Donovan*, 2142–73 [D.C. Cir. 1981]). The case was heading for the court of appeals again, but was settled, with OSHA promising that it would make a good faith effort to issue a final standard in 31 months.

Consistent with its commitments, OSHA commenced rulemaking, and public hearings were held in Washington DC, Florida, Texas, Ohio, and California. Over 200 witnesses were heard, and 4,000 pages of transcript were received. On April 16, 1985, with Robert Rowland under a recess appointment, OSHA published a *Federal Register* notice saying that no final field sanitation standard would be issued. OSHA gave three reasons: Other enforcement priorities would make it difficult for the agency to enforce a field sanitation standard, and therefore future expenditure of resources on the standard would serve no useful purpose; it would be more appropriate under principles of federalism for the field sanitation issue to be regulated by the states; and, finally, OSHA was reluctant to preempt field sanitation standards already issued by states with approved plans (Decision, 50 *FR* 15,086 [1985]). (Because OSHA up to that time had no standard on the issue, there was no preemption.) There was a storm of angry criticism of OSHA, including congressional oversight hearings, and litigation was renewed in the court of appeals in a new proceeding brought by the Farmworker Justice Fund. The public interest brief to the court begins by saying, "It is difficult to imagine an agency action less supported by substantial evidence in the record than OSHA's refusal to adopt the Field Sanitation Standard" (Brief of Migrant Legal Action Program in *Farmworker Justice Fund Inc. v. Brock*, D.C. Cir. No. 85-1349, p. 27 [1985]).

Meanwhile, William E. Brock became secretary of labor, and Robert Rowland left the agency. In October 1985, in a notice signed by Deputy Assistant Secretary Patrick R. Tyson, OSHA set aside its original determination not to issue a standard. The new decision again concludes that state regulation of field sanitation "would be preferable to, and more effective than, federal actions," but this time OSHA gave the states 18 months (until April 1987) to develop and implement field sanitation standards of their own; if the state response was inadequate, as measured by certain criteria established by OSHA, OSHA would within six months issue a federal field sanitation standard (Comment Period Reopened, 50 *FR* 42,660 [1985]). OSHA stated that the state field sanitation standards would have to provide "protection equivalent to the Federal Field Sanitation Proposal of 1984. . . . At the same time," according to OSHA, "specific requirements may vary from the Federal Proposal." Finally, OSHA insisted that the states must have "adequate enforcement programs."

Testifying on November 6, 1985, before a subcommittee of the House Government Operations Committee, Department

of Labor representatives stated confidently that the secretary of labor "has ended, not prolonged, the 13-year debate over field sanitation because he has made an unequivocal commitment to provide additional needed protections to American agricultural field workers" (*OSHA's Failure to Establish a Farmworker Field Sanitation Standard: Hearing Before a Subcomm. of the House Comm. on Government Operations*, 99th Cong., 1st Sess. 79 [1985]).

OSHA's statement was premature, for on February 6, 1987, the Court of Appeals for the District of Columbia decided that OSHA must issue a final field sanitation standard within 30 days. The court angrily stated that the agency had utilized an "arsenal of administrative law doctrines" as a justification for "ricocheting" the case between OSHA and the courts for over a decade. It expressed the hope that its decision would "bring to an end this disgraceful chapter of legal neglect." In particular, the court concluded that OSHA was legally wrong in relying on state action, and had acted unreasonably in delaying the standard for yet another two years in the "unsupported and unrealistic" hope that the states would move *en masse* to issue field sanitation standards (*Farmworker Justice Fund v. Brock*, 811 F.2d 613 [D.C. Cir. 1987]). OSHA issued the field sanitation standard on April 28, and the court then vacated its decision as "moot."

ETHYLENE OXIDE

The ethylene oxide (ETO) proceedings raised several important issues concerning OSHA rulemaking. At the proceedings, on petition from the public interest group Public Citizen, the court of appeals in 1983 directed OSHA to initiate rulemaking on the carcinogenic substance within 30 days of the decision. The court said, "Three years from announced intent to regulate to final rule is simply too long given the significant risk of grave danger that ETO poses." (*Public Citizen Health Research Group v. Auchter*, 702 F.2d 1150 [D.C. Cir. 1983]). OSHA conducted a rulemaking and at the end of the proceeding was prepared to issue a standard containing a TWA of 1 part per million (ppm) and an STEL of 5 ppm. As required by Executive Order 12,291, OSHA submitted the draft standard for OMB review. Following OMB review, OSHA deleted the STEL. Public Citizen challenged the standard in the court of appeals and argued, among other things, that OMB interference with OSHA rulemaking violated the OSHAct, which gives authority to issue standards to the agency and not to OMB, and that the off-the-record communications between OSHA and OMB violate the procedural requirements for rulemaking by denying parties their right of rebuttal. Significantly, a number of chairpersons of House committees filed a brief as a friend of the court, also arguing against OMB control of health and safety regulation. The Justice Department filed a brief for OSHA, defending the right—indeed, the obligation—of the president to oversee the Executive Department's regulatory actions, to ensure its consistency with national policy. The proper role of OMB as representative of the president in monitoring the Executive Department Agencies has been widely debated and, in the OSHA context, has also been the subject of congressional hearings. For example, the House Government Operations Committee, following hearings in 1983, issued a report entitled "OMB Interference with OSHA Rulemaking." The majority report said that Executive Order 12,291 had been "used as a backdoor, unpublicized channel of access to the highest levels of political authority in the Administration for industry alone." Twelve members of the Committee filed a dissent arguing in defense of the OMB role (*OMB Interference with OSHA Rulemaking, House Government Operations Comm.*, H.R. Rep. No. 98, 98th Cong., 1st Sess. [1983]).

On July 25, 1986, the Court of Appeals for the District of Columbia issued a major decision, *Public Citizen Health Research Group v. Tyson*, 796 F.2d 1479 (D.C. Cir. 1986), affirming OSHA's long-term exposure limit for ethylene oxide but concluding that OSHA's decision not to set an STEL was not supported by the record and remanding the issue to OSHA for further proceedings. In view of this disposition, the court found it unnecessary to decide the "difficult Constitutional questions concerning the Executive's proper role in administrative proceedings" and the proper scope of power delegated by Congress to certain executive agencies. Meanwhile, OMB's activity in the rulemaking led to consideration in Congress in the form of legislation proposed by Senators Levin, Durenburger, and Rudman. The bill, entitled "The Rulemaking Information Act of 1986" (S. 2033), would require the disclosure to the public of a number of documents exchanged between OMB and executive agencies in the process of review by OMB of agency rules under Executive Order 12,291. At the same time, the House Energy and Commerce Subcommittee on Oversight and Investigation was investigating allegations that OMB interfered with cancer risk assessment guidelines being prepared by OSHA and other regulatory agencies. In response to these actions, OMB agreed in June 1986 to disclose to the public certain information pertaining to its review process.

On July 21, 1987, the court of appeals directed OSHA to issue a final rule on the short-term exposure issue by March 1988 or face a contempt citation (17 *OSHR* 237-238, 1987).

Safety Standards

A number of actions have been taken on safety standards since 1981. Some were the promulgation of new standards: on marine terminals in July 1983, servicing single and multipiece wheel rims in February 1984, and electrical standards for the construction industry in 1986 (the electrical standard has been challenged in court). Other actions were amendments limiting earlier standards—in particular, exemptions to the diving standards for educational diving issued in November 1982 and revocation of "should" standards in February 1984. In September 1986, OSHA amended its accident tag requirements to provide employers with more

flexibility in meeting the standard (51 *FR* 33,251 [1986]). Finally, rulemaking continued in other safety areas, but disputes with OMB led to extensive delays, and no final standards were promulgated; these included oil and gas drilling and grain elevators, the latter an issue that had been high on OSHA's agenda since the grain elevator explosions in 1975 (*Oversight of the OMB Regulatory Review and Planning Process: Hearings Before the Subcomm. on Inter-Governmental Relations of the Senate Governmental Affairs Comm.*, 99th Cong., 2nd Sess. 1–58 [1986]: 16 OSHR 260, 15 OSHR 557 1985).

The Federal Program

OSHA recently has undertaken a number of new initiatives in the area of federal employee safety and health, primarily on the basis of the expansion of its authority in a 1980 executive order. In 1983, OSHA revised its staff manual, outlining three types of federal agency inspections that would be conducted by OSHA: unannounced inspections in response to employee reports of hazardous conditions, fatality and catastrophe inspections, and inspections of targeted high-hazard workplaces. The number of OSHA inspections has continued to rise; in fiscal 1985, OSHA conducted 1,883 inspections (*OSHA Oversight, Status of Federal Agency, Health and Safety Programs: Hearings Before the Subcomm. on Health and Safety of the House Comm. on Education and Labor*, 99th Cong., 1st Sess. 2-3 [1985] [referred to hereafter as OSHA *Oversight, Status of Federal Agency, 1985]; The President's Report on Occupational Safety and Health*, 1985). OSHA not only inspects federal agency workplaces but evaluates the "complete safety and health programs" of federal agencies. For example, in 1985 OSHA conducted a full evaluation of the Agriculture and Interior Departments and conducted a follow-up evaluation of the programs of the Tennessee Valley Authority, the Postal Service, and the Navy Department (*OSHA Oversight, Status of Federal Agency*, 1985, pp. 8–9).

In 1983, important changes were made to OSHA's practice in reporting on federal injury and illness rates. Previously, the annual statistical report was based on data submitted to OSHA by the agencies. Beginning in 1984, however, OSHA no longer required the submission of data and used as a basis for its surveys compensation claims data that had already been submitted to the Department of Labor by the agencies. Using this new method, OSHA concluded that the incidence rate for all federal civilian employee injuries and illnesses stayed essentially the same from fiscal year 1984 to 1985 (5.77 in 1984; 5.65 in 1985). However, the lost workday case incidence rate dropped from 2.91 to 2.6 percent, continuing a downward trend that began in 1980. OSHA also reported on related statistics on employee compensation charge-back costs. In 1985, the rate of growth increased substantially to 10 percent, although OSHA in its 1986 statistical report asserted that this was not caused by an increase in the number of claims filed.

Criticism of OSHA's efforts continued, with Michael Urquhart, president, Local 12, American Federation of Government Employees, telling a House subcommittee in 1985 that OSHA "has abandoned the goal of reducing worker injuries and illnesses and instead is pursuing the goal of reducing workers' compensation costs." He asserted that the reduction of workplace risks involves commitment, resources, and leadership, "three things we find sorely lacking in OSHA's federal agency program today" (*OSHA Oversight, Status of Federal Agency*, 1985, p. 17).

BLS Statistical Survey

In November 1986, BLS reported that its 1985 injury and illness survey showed virtually no change in the injury and illness rates between 1984 and 1985; in 1985, there were 7.9 injuries and illnesses for every 100 full-time workers as compared to 8 in 1984. The actual number of injuries and illnesses increased by 1.6 percent, but the rate did not increase because of the increased number of workers and hours of work. Assistant Secretary Pendergrass saw the data as affording encouragement to OSHA on the "course we have mapped out" for the agency. The AFL–CIO, on the other hand, termed the results disappointing, focusing on increases in the service industries, where employment growth had occurred (16 *OSHR* 628, 1986).

In the meantime, serious questions have arisen over the accuracy of the data of injuries and illnesses that are being submitted by employers to BLS. An expert panel under the National Academy of Sciences was asked to report at the end of 1987 on a number of issues related to the record-keeping and reporting system. Labor unions have charged that employers seriously underreport injuries and illnesses, which not only distorts BLS statistics but also results in inappropriate exemptions from OSHA inspection activity. The unions argue that their assertions are confirmed by a number of major OSHA citations and penalties for willful violations of the record-keeping regulations; in January 1987, for example, a large automobile company agreed to pay a $295,000 penalty for record-keeping violations, reduced from $910,000, and in July, OSHA proposed a record $2.59 million fine against a meatpacking company for alleged intentional failure to record 1,000 worker injuries (17 *OSHR* 235, 1987).

In an effort to study the accuracy of BLS statistics, OSHA conducted a pilot program to examine the injury and illness records of 200 employers and compare them with a "reconstructed" picture of the actual number of injuries and illnesses, based on interviews and other records (16 *OSHR* 880-82, 1987).

1987 TO THE YEAR 1995: REEVALUATING OSHA

On December 26, 1990, OSHA observed its twentieth anniversary. (The OSHAct was approved by President Nixon on December 26, 1970, and took effect April 28,

1971.) On this occasion, the agency was saluted for its many accomplishments, having raised the consciousness of the public on the issue of occupational safety and health. Concurrently, however, these commendations were tempered by broad recognition that much remained for OSHA to do, and that in a number of areas, the agency's performance was disappointing.

John Pendergrass, a health professional, became assistant secretary of OSHA on May 22, 1986. During his term of office, the agency moved away from the deregulatory policies that had been emphasized during much of the Reagan Administration, particularly during the tenure of Assistant Secretary Thorne Auchter. The major project undertaken during Pendergrass's administration was the rulemaking to update the more than 400 OSHA air contaminant standards originally issued in 1971. Although this precedent-setting standards project was completed by the agency in an expedited fashion, it ended in disappointment when the entire rule was invalidated in 1992 by the United States Court of Appeals for the Eleventh Circuit. As a result, OSHA was forced to reinstitute its largely outdated 1971 permissible exposure limits. This legal setback cast serious doubt on all of OSHA's efforts to use generic rulemaking to expedite the promulgation of standards and, it has been argued, greatly added to the urgency of the need to amend the OSHAct (which is discussed later in the chapter).

Pendergrass resigned on March 31, 1989, and was replaced by Gerard Scannell, who served as assistant secretary from November 1989 until January 1992. Scannell had served as a high official in early OSHA administrations and, later, as a safety director in private industry. During his administration as assistant secretary, OSHA gave special emphasis to its compliance efforts, and in 1990 the OSHAct was substantively amended for the first time, with the maximum amounts of penalties increased by a factor of seven. Scannell also expanded the use of OSHA's "egregious" penalty policy, which, together with the amended penalty provisions, led to greatly increased penalties in certain cases, thus significantly increasing the credibility of the agency's enforcement program. During the Scannell Administration, the agency responded to a series of tragic petrochemical facilities explosions with a special-emphasis compliance program for that industry and, simultaneously, by developing and issuing a new chemical industry process safety management standard. In 1991, OSHA issued a bloodborne pathogens standard, directed at the hazards of the HIV and hepatitis-B viruses. The agency has also initiated a number of activities directed at ergonomics hazards, which increasingly have been recognized as a serious occupational safety and health issue.

When Scannell left office in 1992, his administration of the OSHA program was widely praised by representatives of labor, management, and a wide variety of other interested groups. There was no appointment of a new assistant secretary during the later part of the Bush Administration, and it was not until June 1993 that President Clinton announced his intention to appoint Joseph Dear, a former official of the Oregon state OSHA program, as assistant secretary.

Dear was not sworn in as assistant secretary of OSHA until November 1993, 22 months after Scannell left office. During the interim period, OSHA was run by a number of acting directors.

On assuming office, Dear described his vision for the agency, which included streamlining the standards process, more effective targeting, and promotion of worker–management cooperation in the workplace. He also said that he would emphasize criminal enforcement and implementation of "egregious" penalties. In the early months of the Dear Administration, there was considerable discussion of the possibility that OSHA reform legislation would finally be passed. However, with the bitter partisan controversy in Congress over a variety of matters, particularly health care reform, the OSHA legislation never reached the floor, and barely one year after Dear assumed office, after the Republican victory in Congress, he spoke of the need to reassess the OSHA program in light of "political realities."

As we approach the beginning of 1996, the future of OSHA is, to say the least, uncertain.

Supreme Court Decisions

Throughout the history of OSHA, decisions of the U.S. Supreme Court have played a key role in the direction of OSHA policy. During the 1987–1993 period, the Court decided four cases under the OSHAct or involving issues closely related to occupational safety and health.

The first of these, decided on February 21, 1990, involved the authority of the Office of Management and Budget (OMB) under the Paperwork Reduction Act (*Dole v. United Steelworkers of America*). OMB, in reviewing OSHA's expanded hazard communication standard under the Paperwork Reduction Act, disapproved three of its provisions relating to material safety data sheets (MSDSs). This disapproval was challenged by the Steelworkers Union, and the Supreme Court in a split decision agreed with the union and ruled that OMB had acted beyond its statutory authority.

Under OSHA's hazard communication standard, MSDSs must be prepared by employers and made available to employees to inform them of the chemical hazards to which they are exposed. OMB disapproved of OSHA's MSDS requirements applicable to multiemployer worksites, concluding that they increased the paperwork burdens of employers and were not necessary to protect employees. The Supreme Court rejected OMB's interpretation of the Paperwork Reduction Act and ruled that OMB authority under that law was limited to the review of information-collection requirements imposed by a federal agency where the information was for the agency's own use. In OSHA's hazard communication standard, however, the information in the required MSDSs was for the benefit of employees, and the MSDSs were not submitted to OSHA. These requirements

were therefore not subject to OMB review, the Court held. Justice White and Chief Justice Rehnquist dissented.

The second case was that of *United Auto Workers v. Johnson Controls Inc.* Handed down by the Supreme Court on March 20, 1991, it was decided under Title VII of the Civil Rights Act of 1964. In that case, the employer had instituted a policy, called the fetal protection policy, that excluded women of childbearing age from areas of the facility involving exposure to lead. The employer argued that the policy was necessary to protect fetuses from harmful exposures to lead, relying on studies showing that lead in a pregnant woman's bloodstream could be transmitted to the fetus through the placenta. The Court rejected the employer's justification for the policy and invalidated the fetal protection policy under Title VII.

The court concluded that the fetal protection policy was discriminatory because it singled women out for special treatment in the face of scientific findings that lead exposure also had adverse reproductive effects on males. The fetal protection policy was not a bona fide occupational qualification under Title VII, the Court further held, because both fertile and infertile women were equally capable of efficient work at a lead battery facility. In thus holding that employment discrimination based on reproductive potential is equivalent to explicit sex discrimination and unlawful, the Supreme Court resolved disagreements among several courts of appeals, and its conclusion was consistent with statements in OSHA's 1978 lead standard. In that standard, OSHA recognized the dangers of exposure to lead for both men and women, and explicitly stated that the standard was not intended to justify the exclusion of women of childbearing age from the workplace.

Under the OSHA statutory scheme, agency citations and penalties are initially reviewed by the Occupational Safety and Health Review Commission (OSHRC), whose decisions are further reviewed by U.S. courts of appeal. Such review often involves the interpretation by both OSHRC and the courts of standards promulgated by OSHA. A well-established principle in administrative law requires that courts defer to the interpretations by an administrative agency of its own regulations and standards. In the case of OSHA, however, there was a difference of opinion between OSHA and the Review Commission and among the courts as to whether the courts should defer to the interpretations of OSHA or to those of OSHRC, because both are administrative agencies under the OSHAct.

The issue was resolved in *Martin v. Occupational Safety and Health Review Commission*, decided on March 20, 1991, which involved an interpretation of OSHA's coke oven standard. OSHRC had rejected OSHA's interpretation of the standard and dismissed OSHA's citation, and the Court of Appeals for the Tenth Circuit deferred to the Review Commission's interpretation. The Supreme Court reversed the decision. The Court held that a "necessary adjunct" to OSHA's statutory authority to issue standards was the power to render authoritative interpretations of those standards. This conclusion was based partly on the statutory structure of the OSHAct and, further, on the practical consideration that because OSHA develops and promulgates standards and enforces these standards, it is in a far better position than the Review Commission, which merely adjudicates cases, to interpret the standards. Accordingly, the Supreme Court held that a court must in the first instance defer to "reasonable" interpretations of standards by OSHA; only if OSHA's interpretation is deemed unreasonable should the court rely on OSHRC's interpretation.

The fourth case, *Gade v. National Solid Wastes Management Association*, was decided on June 19, 1992. It involved the issue of OSHA's preemption of state OSHA enforcement. OSHA had promulgated a final standard protecting employees engaged in hazardous waste operations. The state of Illinois, which does not have an approved state plan, enacted two statutes requiring the licensing of certain hazardous waste equipment operators and laborers. The stated purpose of the legislation was to protect both the employees involved and the general public. (This became known as a dual-purpose statute.) The issue in the case was whether the federal OSHAct preempted the Illinois statutes.

The Supreme Court held that the state statutes were preempted. It first rejected the argument offered by Illinois and unions that OSHA preempts only conflicting state occupational safety and health regulations. Following lower court precedent, the Court held that federal OSHA preempts all state occupational safety and health regulation on an issue covered by an OSHA standard. The Court went on to reject the state argument that dual-purpose state regulations are not preempted because they also have a nonoccupational purpose. The Court said that a state law that "directly, substantially, and specifically" regulates occupational safety and health is an occupational safety and health law, and it is not any less so for preemption analysis by virtue of the fact that it may also have a nonoccupational impact. Four Supreme Court justices dissented.

Standards Activity: Health Standards

AIR CONTAMINANTS

OSHA's major effort to update its 1971 air contaminants standards ended in disappointment when the Court of Appeals for the Eleventh Circuit in July 1992 decided that the agency's action was invalid under the OSHAct.

In 1971, OSHA adopted as start-up health standards approximately 400 PELs for various toxic substances. These were based for the most part on the Threshold Limit Values® (TLVs®) developed by the American Conference for Government Hygienists (ACGIH) in 1969 and subsequently adopted by the Department of Labor as established federal standards under the Walsh–Healey Act, a predecessor to the OSHAct. Although these PELs were important in providing the agency with a basis for prompt enforcement after enactment of the then-new OSHA statute, over the years significant problems

developed as OSHA relied on these standards as a primary basis for OSHA enforcement. By the 1980s, these PELs were in many cases outmoded, providing completely inadequate protection to employees. Although permissible levels for some substances had been updated in substance-specific proceedings, most had not, and it was generally agreed that it would be highly impractical for the agency to embark on individual rulemaking proceedings to update PELs for hundreds of toxic substances. Furthermore, the 1971 health standards contained none of the ancillary provisions such as requirements for medical surveillance and exposure monitoring that have since been routinely contained in separately issued OSHA health standards.

In 1988, OSHA, responding to this unsatisfactory situation, began one of the most extensive rulemakings in its history, proposing to update the 1971 PELs. In January 1989, after expedited rulemaking proceedings, OSHA published a final revised air contaminants standard, in which it required lowered permissible limits for 212 substances included in the 1971 standard, and established new limits for 164 substances not previously regulated in the earlier standard. The new air contaminant standard became effective in September 1989, but the requirement for implementation of engineering controls to meet the new limits was not scheduled to be effective until January 1993. (The new standard did not adopt ancillary requirements for the regulated substances, reserving those for further generic or individual rulemakings.)

Both industry and union groups sought review of the rule updating the PELs, and the review proceeding was transferred to the Court of Appeals for the Eleventh Circuit.

On July 7, 1992, in a far-reaching decision, the court of appeals unanimously vacated the entire air contaminants rule. Although concluding that generic rulemaking was not an inappropriate way for OSHA to issue standards, the court held that in the proceeding under review the agency had failed to meet the specific statutory requirements for rulemaking. The court ruled that, in effect, OSHA had issued 428 individual standards but that it had failed to establish that each of the standards addressed a significant risk in the workplace, as required by the Supreme Court benzene decision, or that the levels were feasible for the industrial operations covered. The court later denied a motion for reconsideration of its decision, and further efforts by OSHA to delay the effective date of the decision were not successful.

OSHA then held further discussions with the Office of the Solicitor General, urging appeal to the U.S. Supreme Court, but the solicitor general ultimately decided that the case was not appropriate for Supreme Court review. So, in March 1993, OSHA advised the public and OSHA field staff that the 1989 revised PELs were not in effect, and that the agency would return to the 1971 levels for enforcement purposes.

Meanwhile, shortly before the decision of the Court of Appeals for the Eleventh Circuit, OSHA had published in the *Federal Register* a lengthy proposal to update the permissible levels for air contaminants in the construction and maritime industries and agriculture. The air contaminant standard issued in 1989 did not apply to these sectors, and many permissible exposure limits in construction, maritime, and agriculture either did not exist or were out of date. When the court of appeals vacated the general-industry air contaminant standard, OSHA suspended further action on the proposal to update the levels in the other three industries.

BLOODBORNE PATHOGENS

An important new OSHA priority in the health standards area has been on workplace hazards resulting from infectious diseases. In 1991, OSHA successfully completed rulemaking and issued a final standard addressing occupational exposure to bloodborne pathogens, particularly the hepatitis-B virus and the human immunodeficiency virus (HIV). The standard was upheld for the most part by the Court of Appeals for the Seventh Circuit in February 1993.

OSHA was petitioned in September 1986 to issue an emergency temporary standard for bloodborne pathogens. OSHA rejected the petition but commenced rulemaking on the issues, publishing an advanced notice requesting information in 1987 and a proposed bloodborne pathogen standard in May 1989. The agency announced that during the rulemaking it would enforce existing regulations and the general duty clause to help prevent workplace transmission of bloodborne diseases. Great public interest was shown in the rulemaking; hearings were held in five cities and more than 400 persons testified at the hearings. The record was extensive.

OSHA promulgated the final Bloodborne Pathogens Standard on December 6, 1991 (56 *FR* 64004). The standard contains detailed provisions for the protection of employees, mainly health care workers, from hazards resulting from exposure to the hepatitis-B and HIV viruses. Among these provisions are the availability, without charge, of hepatitis-B vaccines to all employees within 10 days of assignment to jobs involving exposure to blood; engineering controls such as puncture-resistant containers for used needles; work practice controls such as hand-washing for exposed employees; requirements for use of personal protective equipment including gloves, masks, and gowns; postexposure evaluations; hazard communication requirements, including signs and warning labels; and record-keeping requirements.

In a decision dated January 28, 1993, the Court of Appeals for the Seventh Circuit upheld OSHA's bloodborne pathogens standard except in one respect. Judge Coffey dissented. In his opinion for the court, Judge Posner first noted that most health care employers had already voluntarily accepted the provisions of the OSHA standard, which was based largely on the recommendations of the Centers for Disease Control (CDC) of the National Institutes of Health, even before they had become OSHA requirements. The court analyzed in detail and rejected all of the arguments of

the American Dental Association, which challenged the standard, concluding that the OSHA standard, "accepted as it has been by most health care industries and based as it is on the recommendations of the nation's, perhaps the world's, leading repository of knowledge of infectious diseases," does not cross the "boundary of reasonableness." The majority, however, remanded to OSHA the question raised on appeal by those employers who provide to employees worksites not under their control, as, for example, home health care workers. The court directed the agency to address more specifically the extent of the responsibility of these employers for compliance with the standard.

ASBESTOS

Asbestos has been the subject of OSHA regulation since the earliest days of the agency. In June 1986, OSHA issued a revised asbestos standard, sharply lowering the PEL from 2 fibers per cubic centimeter (cc) to 0.2 fibers per cc. The new standard was quickly challenged by both employer groups and unions, but, in an important decision, the Court of Appeals for the District of Columbia upheld the standard in most respects. However, on several issues, the court returned the proceeding to OSHA for further consideration to determine, generally, whether more protective provisions should be added.

OSHA's response to the court remand has continued over a period of several years and is not yet complete. The first issue to be reconsidered by OSHA was the short-term exposure limit (STEL). In September 1988, the agency promulgated a 1-fiber/cc short-term limit averaged over a 30-minute sampling period. In 1989 and in 1990, OSHA responded to several additional remand issues by amending the asbestos standard. Among other things, they expanded the ban on workplace smoking and required employer training programs on smoking and warning signs and labels.

The most controversial aspect in the court remand was the issue of the appropriate 8-hour PEL. The court of appeals had directed the agency to consider whether a permissible limit more protective than the 0.2 fiber/cc PEL established in the standard was feasible, either generally or for specific industrial operations. On remand, OSHA initially decided that it could not determine this issue without further rulemaking, and in July 1990 it published a proposal lowering the PEL from 0.2 to 0.1 fibers/cc for all industries. Hearings on the proposals were held and public comment received. Final action was taken on the proposed revision on August 10, 1994. At that time, OSHA issued amended standards for asbestos in general industry and in the construction industry and a new asbestos standard for the shipyard industry. The principal revision in the new standard was a reduced PEL of 0.1 fiber/cc for asbestos work in all industries, which was half of the earlier 0.2 fiber/cc limit. Also significant was the new requirement that the building and facility owners communicate their knowledge of the location and presence of asbestos-containing materials or of certain high-risk materials presumed to contain asbestos, to employers of workers who may be exposed to those materials.

A number of industry groups and two unions challenged the new asbestos standard, and the appeal is pending in the Court of Appeals for the Fifth Circuit.

Meanwhile, OSHA has also reconsidered the application of the asbestos standard to the nonasbestiform substances tremolite, anthophyllite, and actinolite. They were covered by the original 1986 asbestos standard, but in response to legal challenge, the application of the standard to these substances was stayed. In June 1990, OSHA, following additional rulemaking, amended the asbestos standard by removing the nonasbestiform substances from its scope. The agency concluded that substantial evidence was lacking that these substances present the "same type or magnitude of health effects as asbestos." In the future, the agency said, these nonasbestiform substances will be regulated under other applicable OSHA dust standards.

ETHYLENE OXIDE

OSHA's ethylene oxide standard was originally issued in June 1984. In 1986 the Court of Appeals for the District of Columbia upheld the standard but determined that OSHA's decision not to issue a short-term exposure limit was not supported by the record, and remanded the proceeding to OSHA for reconsideration of the STEL issue. When after a year OSHA had still failed to take action on the court remand, the court of appeals, showing considerable impatience, ordered OSHA to act on the STEL by March 1988 or face contempt action. On April 6, 1988, OSHA promulgated a 5-ppm STEL, measured over a 15-minute sampling period, for ethylene oxide (53 *FR* 11414).

LEAD

OSHA's original revised lead standard was promulgated in 1978. The standard established a limit of 50 $\mu g/m^3$ of air averaged over an 8-hour period for all industries except construction. Although the Court of Appeals for the District of Columbia generally upheld the standard, in a wide-ranging 1980 opinion it remanded the proceeding to OSHA for consideration of the feasibility of the standard in nine specified industries. After a number of delays and further rulemaking in 1989 and 1990, the agency determined that the lead standard's 50-$\mu g/m^3$ PEL was feasible in all remanded industries except for the small foundry segment of the nonferrous industry. OSHA established a 75-$\mu g/m^3$ limit in that industrial segment. This supplemental determination by OSHA was challenged, but in another decision on the lead standard, the Court of Appeals for the District of Columbia upheld OSHA's feasibility determinations, except as to the brass and ingot industry. For that industry, the court vacated the requirements for engineering controls and held that, in the meantime, the 50-$\mu g/m^3$ limit could be met by a combination of engineering, work practice, and respirator controls.

OSHA has also been concerned about lead hazards in the construction industry—the revised 1978 standard did not cover construction operations, and the applicable construction PEL was four times higher than the general industry standard. OSHA had begun work on a proposed standard on lead for construction when, in October 1992, Congress concluded that the matter was urgent, and passed the Housing and Community Development Act, which required OSHA to issue a construction industry interim lead standard within six months of enactment. Acting under this legislation, OSHA, on May 4, 1993, without rulemaking, published an interim lead standard that lowered the PEL for lead in construction to a 50-μg/m^3 level—the same level applicable to general industry (58 *FR* 26590). The standard also includes the same monitoring and medical removal provisions as for general industry. Under the 1992 statute, this interim standard would be effective immediately.

FORMALDEHYDE

In December 1987, after extensive rulemaking, OSHA published a comprehensive standard regulating formaldehyde. Among other requirements, the standard established a 1-ppm 8-hour PEL and a 2-ppm short-term limit. The standard was challenged both by industry and by a number of unions, and the Court of Appeals for the District of Columbia remanded the proceeding to OSHA for reevaluation of two issues:

- The 1-ppm PEL—the court said OSHA must establish a lower PEL if it determined that a significant risk remained at 1 ppm and a lower PEL was feasible.
- Provision for medical removal protection, which OSHA had failed to include in the standard.

Following the remand, the opposing parties to the proceeding made recommendations to the agency for resolution of the issues pending under the remand. OSHA then proposed changes in the standard that were based on the parties' recommendations, and on May 27, 1992, issued a final rule amending the Formaldehyde Standard (587 *FR* 22290). The rule incorporated the substance of the parties' recommendations and lowered the PEL from 1 ppm to 0.75 ppm. The final standard also provided medical removal protection to employees suffering from certain illnesses resulting from exposure to formaldehyde.

HAZARD COMMUNICATION

OSHA's 1983 hazard communication standard has been subject to extensive litigation and has been amended by the agency several times. In 1987, following a decision of the Court of Appeals for the District of Columbia, OSHA expanded the coverage of the hazard communication standard to include all industries and all employees exposed to hazardous chemicals. In November 1988, the Court of Appeals for the Third Circuit upheld the expanded hazard communication standard against challenges filed by the construction and grain industries. Earlier, OMB had disapproved three provisions of the expanded standard, notably the requirement that material safety data sheets be provided to all employers on multiemployer worksites. OMB's authority to disapprove a standard's provision in these circumstances was challenged, and ultimately the U.S. Supreme Court rejected OMB's argument that the Paperwork Reduction Act gave OMB adequate authority to review these requirements (*United Steelworkers v. Dole*, discussed previously).

In August 1988, OSHA published a proposal asking for comment on the issues raised by OMB in its disapproval of provisions in the hazard communication standard and for general comment on the expanded coverage of the standard to nonmanufacturing industries. Public hearings were held and comments received on this proposal, and on February 9, 1994, OSHA promulgated a final rule modifying in several respects the 1987 hazard communication standard.

Meanwhile, concerns had been expressed to OSHA about the usefulness of the material safety data sheets (MSDSs) required under the hazard communication standard. In May 1990, OSHA responded to these concerns by publishing a Request for Information that asked for comment on improving the presentation and quality of chemical hazard information under the hazard communication standard. Many comments were received, and OSHA also commissioned consultant studies on the accuracy of the MSDSs.

LABORATORY SAFETY AND HEALTH

In July 1990, OSHA published a final standard (29 *CFR* 1910.1450) regulating employee exposure to hazardous chemicals in laboratories (55 *FR* 3300). The standard requires continued compliance with PELs for hazardous substances, and although it does not itself establish any new PELs, it requires the development and implementation of a chemical hygiene plan, tailored to the individual workplace, that includes work practices and procedures to protect laboratory employees.

COTTON DUST

Although the U.S. Supreme Court had affirmed OSHA's cotton dust standard in major respects in a 1980 decision, the agency proceeded to reevaluate the standard, publishing proposed revisions in 1983. In 1985, OSHA published final amendments to the cotton dust standard, but with respect to the most controversial issue in the rulemaking, the agency adhered to its existing policy that engineering controls were the preferred means of reaching the PEL. In two decisions in 1987, the Court of Appeals for the District of Columbia upheld provisions of the amended cotton dust standard. Rejecting a challenge of the Minnesota Mining and Manufacturing Company, the court upheld the standard's respiratory selection provisions. The court of appeals also affirmed OSHA's decision to retain medical surveillance requirements for the cottonseed industry, even though OSHA did not find a significant risk in that indus-

try and, as a consequence, did not establish a PEL for the industry.

CADMIUM

In June 1986, OSHA was petitioned to issue an emergency standard to reduce employee exposure to cadmium. OSHA rejected the request, and this action was upheld by the Court of Appeals for the District of Columbia, after which OSHA undertook a section 6(b) rulemaking on cadmium. In February 1990, OSHA published a proposal suggesting two alternative PEL levels for cadmium, 5 $\mu g/m^3$ or 1 $\mu g/m^3$, both based on the carcinogenicity of the substance. When, following public comment and hearings, OSHA delayed the issuance of a final cadmium standard, the agency was ordered by the Court of Appeals of the District of Columbia, on the petition of a union and a public interest group, to issue a final cadmium standard by August 31, 1992. The final standard was published in the *Federal Register* on September 14, 1992 (57 *FR* 42102).

OSHA's final cadmium standard includes one tier for general industry, maritime, and agriculture and a separate tier for construction. Both tiers of the standard provided a PEL of 5 $\mu g/m^3$ and an action level of 2.5 $\mu g/m^3$, with the action level triggering certain protective requirements such as exposure monitoring and medical surveillance. In light of the different working conditions in the construction industry, the construction portion of the standard contained specific provisions uniquely tailored to conditions in that industry.

Seven challenges to the cadmium standard were filed in court. Six were settled without litigation, and, on March 22, 1994, the Court of Appeals for the Eleventh Circuit upheld the standard except in one respect; the court ruled that although OSHA was justified in including cadmium pigments in the standard, the record did not establish the technological and economic feasibility of the standard in the dry color formulator industry. The proceeding was remanded to OSHA for further consideration of the feasibility issue.

OTHER HEALTH STANDARDS

In July 1980, the U.S. Supreme Court vacated OSHA's benzene standard in one of its most significant regulatory decisions of the decade. More than seven years later, in an action described as "landmark" by Assistant Secretary Pendergrass, the agency, after rulemaking, issued a new benzene standard reducing the PEL from 10 ppm to 1 ppm, the same PEL that had been vacated by the Supreme Court almost a decade earlier. The new standard also established a short-term exposure limit for benzene of 5 ppm (52 *FR* 34460). In its preamble to the standard, OSHA stated that it had found a significant risk to employees who were exposed to benzene at existing levels, and that promulgation of the new PEL would substantially reduce that risk. (The Supreme Court in its 1980 decision had for the first time imposed the "significant risk" requirement, and vacated the original benzene standard because of OSHA's failure to make the significant risk finding.) Several court challenges were filed to the 1987 benzene standard but were later withdrawn, and the 1-ppm PEL for benzene finally went into effect on December 10, 1987.

On May 12, 1989, OSHA published a proposed standard regulating methylenedianiline (MDA). The proposal was based substantially on the recommendations of a mediated rulemaking committee established by the agency and representing interested parties. This was the first successful attempt by OSHA to use mediated rulemaking in the development of a proposed standard. Mediated rulemaking is intended to help OSHA reach consensus in rulemaking and speed up the issuance of standards. However, largely because of OMB review, there was considerable delay before the proposed MDA standard was published, and the advantages of mediated rulemaking were partly vitiated (57 *FR* 35630). The final standard was for the most part based on the committee recommendations. Separate standards were issued for general industry and construction, but they were similar in important respects, both establishing a PEL for MDA of 10 million parts per billion. This PEL is based on animal and human studies demonstrating that MDA poses carcinogenic risks.

Several health standard proceedings are currently pending before the agency. On August 10, 1990, after rejecting a petition for an emergency standard, OSHA published a proposed standard on butadiene. The proposed standard would lower the PEL for butadiene to 2 ppm, with a short-term limit of 10 ppm.

In November 1991, OSHA published a proposed standard regulating methylene chloride. Based on animal studies showing the carcinogenicity of the chemical, OSHA's proposal would reduce the PEL to 25 ppm, delete the existing ceiling, and provide a short-term limit of 125 ppm for a 15-minute period. OSHA has received public comment and held hearings on both of these proposals, but no final standards have been issued.

The issue of indoor air pollutants is a significant one, particularly in light of studies showing the harmful effects of passive smoking. After the Court of Appeals for the District of Columbia upheld OSHA's decision not to issue an emergency standard on smoking in the workplace, the agency, in September 1991, published a Request for Information on indoor air pollutants. The request asked for data on four air contaminants: chemical agents, bioaerosols, passive tobacco smoke, and radon. During the last several sessions of Congress, legislation has been introduced to regulate indoor air quality.

On April 5, 1994, in the *Federal Register*, OSHA promulgated a Notice of Proposed Rulemaking (NPRM) to address air quality in indoor work environments. The provisions of the proposed indoor air quality (IAQ) standard apply to all indoor "nonindustrial work environments." In addition, all worksites, both industrial and nonindustrial, within OSHA's jurisdiction are covered with respect to the proposed provisions addressing control of environmental tobacco smoke (ETS).

OSHA's IAQ proposal would require covered employers to develop a written indoor air quality compliance plan and implement that plan through actions such as inspection and maintenance of heating, ventilation, and air-conditioning (HVAC) systems. Employers would be required to implement controls for specific contaminants and their sources, such as outdoor air contaminants, microbial contamination, maintenance and cleaning materials, pesticides, and other hazardous chemicals within indoor work environments.

Designated smoking areas, which are to be separate, enclosed rooms exhausted directly to the outside, are required in buildings in which the smoking of tobacco products is not prohibited. Specific provisions are also proposed to limit the degradation of IAQ during the performance of renovation, remodeling, and similar activities. Provisions for information and training of HVAC system maintenance and operations workers and other employees within the facility are also included in OSHA's IAQ proposal.

Finally, proposed provisions in this notice address the establishment, retention, availability, and transfer of records; for example, inspection and maintenance records of written compliance programs and employee complaints of building-related illnesses.

A record-breaking number of comments were received on the proposed standard, and after a postponement, the public hearing commenced on September 20, 1994. Meanwhile, on July 12, 1994, the Court of Appeals for the District of Columbia rejected as unripe for judicial review a claim by Action for Smoking and Health, a public interest group, that OSHA acted arbitrarily in proposing to regulate environmental tobacco smoke together with other air contaminants. The group's argument, which the court found to be premature, was that the regulation of tobacco smoke would be unreasonably delayed by the omnibus regulation.

In other actions, OSHA has denied petitions for emergency standards for chromium and tuberculosis hazards, but has asserted that both have a high priority and that rulemaking would be initiated to regulate each of these hazards.

Standards Activity: Safety Standards

PROCESS SAFETY MANAGEMENT FOR HAZARDOUS CHEMICALS

In response to a series of tragic workplace explosions at a number of chemical facilities in 1989 and 1990, which resulted in more than 40 employee deaths and numerous injuries, OSHA took a number of major steps in both the enforcement area and in the development of standards to protect employees from such occurrences. In July 1990, the agency issued a proposed chemical process safety management standard based on data it had received from a variety of sources including industry and labor. Meanwhile, Congress held oversight hearings to investigate the causes of the facility explosions. In the Clean Air Act Amendments, enacted into law in November 1990, Congress directed OSHA to complete its rulemaking on a process safety management (PSM) standard within one year of enactment. The statute also prescribed 14 provisions that the agency was required to include in the PSM standard.

Hearings on OSHA's proposed standard were held in 1990 and 1991 in Washington DC and in Houston, Texas, and an extensive rulemaking record was compiled. One of the major issues in the rulemaking was the adequate protection of employees of contractors working at chemical facilities. Controversy on this issue forced the agency to delay promulgation of the final standard beyond the congressional deadline in order to allow full public comment on a study commissioned by OSHA on contractor employees. The final PSM standard was issued on February 24, 1992 (57 *FR* 6356).

Under the standard, employers are required to conduct systematic analyses of potential hazards in every step of the chemical process and, based on these analyses, to take appropriate steps to prevent chemical explosions or releases. In addition, the standard requires companies to consider safety records in choosing contractors and to institute policies and procedures to ensure the training of contract workers in safety procedures. The new PSM standard also requires that contractors themselves be responsible for training their workers in various chemical processes, in order to protect both the contractor's own employees and the employees of the chemical manufacturer. The standard requires each employer to prepare a hazard analysis covering each chemical process and written operating procedures, including steps for each operating phase and safety systems, and that these be readily available to employees.

The PSM standard was originally scheduled to go into effect on May 26, 1992. OSHA delayed the effective date of seven provisions in the standard until August 26 but, on August 25, announced that it was rejecting a request by various industry groups for a further stay of four provisions until 1994. The PSM standard has been challenged by both industry and unions, but this litigation was settled by the parties and the standard is currently in effect.

LOCKOUT/TAGOUT

On September 1, 1989, OSHA issued a final standard on hazardous energy sources, known as the lockout/tagout (LOTO) standard. The standard requires employers to implement practices and procedures to disable machinery or equipment and to prevent the release of potentially hazardous energy while maintenance and servicing activities are being performed. The standard applies the lockout provisions to equipment that is designed with a lockout capability, and tagout provisions to other types of equipment.

The standard was challenged by both industry and labor, and on July 12, 1991, the Court of Appeals for the District of Columbia remanded the LOTO standard to OSHA. In a lengthy and, in many respects, difficult decision, the court agreed with OSHA that the specific statutory requirements for standards contained in section 6(b)(5) of the act were

applicable only to health standards and not to safety standards such as LOTO. At the same time, the court indicated its concern with OSHA's interpretation of its authority to issue safety standards, because, the court indicated, the broad discretionary authority claimed by OSHA would raise serious constitutional questions with respect to delegation of legislative authority. The court suggested that the agency might wish to consider using cost-benefit analysis as a criterion in safety standards development, in order to limit the scope of its discretion and avoid questions of constitutionality. The court remand directed OSHA to articulate its view of the scope of its authority to issue safety standards, and to reconsider specified portions of the standard in light of its new interpretation of the standard. In September 1991, the court of appeals decided that the standard would remain in effect during the remand.

In suggesting that cost-benefit analysis would be permissible in the development of safety standards, the Court of Appeals for the District of Columbia agreed with the view previously expressed by the Court of Appeals for the Fifth Circuit in its amended decision in the grain dust case. (The Supreme Court cotton dust decision barred cost-benefit analysis for health standards.) On March 30, 1990, OSHA published a response to the court's remand in the LOTO case, rejecting the use of cost-benefit analysis in safety standards. The agency stated in its *Federal Register* notice that there were adequate limits on the scope of its safety standards authority even if it did not resort to cost-benefit analysis. These included feasibility as a lower limit and significant risk as an upper limit in establishing the PEL.

On October 21, 1994, the Court of Appeals for the District of Columbia accepted OSHA's supplemental statement as responsive to the remand and dismissed the petition for review of the LOTO standard. The court held that OSHA, without having to adopt cost-benefit analysis, has recognized adequate constraints on its discretion to issue safety standards, which could meet with objections on constitutional grounds. The court did not rule directly on whether the cost-benefit issue was lawful in standards proceedings.

GRAIN HANDLING

OSHA's original grain-handling standard was issued on December 31, 1987. The standard was designed to prevent or minimize employee deaths and injuries from fires, explosions, and other hazards in grain facilities. The standard was challenged by both industry and labor, and in two decisions in October 1988 and January 1989 the Court of Appeals for the Fifth Circuit upheld the standard in part but remanded the standard to OSHA for reconsideration of two issues. In its standard, OSHA had imposed a 1/8-inch action level of dust in certain particularly hazardous areas in grain facilities. The court directed OSHA to consider whether the 1/8-inch level was feasible and whether, as the unions had claimed, the stricter requirement should be applied on a facility-wide basis.

One of the major issues in the litigation was whether cost-benefit was lawful under the OSHA statute in safety standard development. In its initial decision, the court held that it was not, but in 1990 the court reversed itself, deferring to OSHA's interpretation that safety standards such as grain handling are not subject to the same restrictions on the use of cost-benefit as health standards.

In response to the remand, OSHA subsequently found the 1/8-inch action level feasible for priority areas, and the court of appeals upheld this determination. However, OSHA decided that it did not have sufficient information in the record on the issues of the scope of the 1/8-inch action level. Accordingly, in December 1990, the agency published a Request For Information on whether the action level should be extended to all portions of grain dust facilities. On April 1, 1994, OSHA published a final decision, concluding that the existing record was adequate for decision, and determining on the basis of this record that the action-level trigger for the housekeeping provisions of the grain dust standard should not be expanded beyond the priority areas.

Hazardous Waste Operations

In the 1986 Superfund Amendments and Reauthorization Act (SARA), Congress required OSHA to issue, by a specified deadline, a final standard to protect employees engaged in hazardous waste operations. In a related action, Congress in 1987, in the Omnibus Budget Reconciliation Act (OBRA), required OSHA to provide for certification of training programs for employees involved in emergency response. On March 6, 1989, OSHA issued a final standard on hazardous waste operations and emergency response (known as HAZWOPER). The standard protects employees involved in cleanup operations at uncontrolled hazardous waste sites under government mandate; in certain hazardous waste treatment, storage, and disposal operations; and in any emergency response to incidents involving hazardous substances.

In January 1990, acting under the mandate of the 1987 OBRA, OSHA published proposed rules to establish procedures for accrediting hazardous waste operation training programs. Public hearings were held on the proposal in 1991.

STANDARDS-RELATED TESTING

Under a number of OSHA safety standards, testing for safety is required to determine whether specified equipment and materials are acceptable for workplace use. The original OSHA standards listed two specific national laboratories as qualified to perform these standards-related tests. Over a number of years, several other testing laboratories sued OSHA, claiming that the safety standards were discriminatory in favoring the two specifically listed laboratories. On December 4, 1987, a U.S. district judge gave OSHA 180 days to promulgate procedures that would allow for OSHA's recognition of other laboratories as qualified to certify equipment. OSHA's final standard on the testing and certification of workplace equipment was promulgated on April 12, 1988

(53 *FR* 121020). The standard deletes the two named laboratories from all safety standards and establishes a procedure by which other testing organizations can be accredited as "nationally recognized testing laboratories" for purposes of OSHA standards. A number of laboratories have subsequently gained accreditation by OSHA under the new procedures.

CONFINED SPACES

OSHA's long-delayed final Standard on Confined Spaces was published in the *Federal Register* on January 14, 1993 (58 FR 4462). The proceeding was begun by an advance notice of proposed rulemaking in 1975, and it continued through several OSHA administrations. (The standard's preamble describes in detail the lengthy procedural steps that preceded its issuance.) The standard imposes various safety requirements, including a permit system regulating employee entry into certain confined spaces that are designated by the standard as "permit-required confined spaces" and defined as posing special dangers because their "configurations hamper efforts to protect entrants from serious hazards, such as toxic, explosive or asphyxiating atmospheres." The standard also requires that employers implement a comprehensive confined-space entry program, which must include ongoing monitoring, testing, and communication with employees.

Court challenges to the confined spaces standard were filed by both employer and union groups, but were dismissed by the court on the basis of understandings between OSHA and the parties on the meaning and implementation of the standard.

CONSTRUCTION STANDARDS

Because construction is one of this country's most hazardous industries, OSHA has traditionally accorded special attention to standards to protect construction workers.

In June 1988, OSHA issued a final standard on concrete and masonry construction, removing ambiguities and redundancies in the existing standard and filling gaps in coverage. The new standard incorporates new technology, and specifies all requirements within the text of the standard rather than incorporating national consensus standards by reference (53 *FR* 22612). While the rulemaking on this standard was underway, a tragic accident took place at L'Ambiance Plaza in Bridgeport, Connecticut, involving lift-slab construction. In light of the special hazards involved in that type of construction, OSHA decided to deal with lift-slab construction in a separate rulemaking, and a final standard on that subject was later issued in October 1990 (55 *FR* 42306). The record in the later proceeding included a special report completed by the National Institute of Standards and Technology (formerly the National Bureau of Standards) at the request of OSHA on the causes of the L'Ambiance collapse.

In 1989, OSHA issued three other construction safety standards: one on underground construction, published on June 1, 1989 (54 *FR* 23824); one on powered platforms for building maintenance, published on July 28, 1989 (54 *FR* 31408); and one on excavations, published on October 31, 1989 (54 *FR* 45894). On November 14, 1990, OSHA issued a construction standard covering stairways and ladders in the construction industry (55 *FR* 47660). This standard consolidates into one subpart scattered provisions in other standards and adds a number of new safety provisions. On August 9, 1994, OSHA promulgated a final standard consolidating all of its requirements for protection against falls in the construction industry into a single subpart of the construction safety standards and revising these provisions in a number of respects. In particular, the final standard allowed alternative methods of fall-protection compliance in cases where traditional approaches are inappropriate or unreasonable.

OTHER SAFETY STANDARDS

In March 1988, OSHA promulgated a rule permitting presence-sensing devices on mechanical power presses (53 *FR* 8322). Under the original mechanical power press standard, the operator of the press was required to initiate the stroke of the press by hand or pedal. Under the new standard, a presence-sensing device would be permitted to initiate the stroke when the operator's body was no longer exposed to harm.

In August 1990, OSHA issued a final rule on electrical safety-related work practices (55 *FR* 31984). The standard establishes required work practices for employees whose jobs require them to work with, on, or near electrical equipment, in order to protect them from electric shock, burns, and other electrical accidents. On April 6, 1994, OSHA promulgated a final standard covering personal protective equipment for eyes, face, hands, and feet in general industry.

OSHA has also initiated rulemaking in two major areas involving priority safety issues. These are ergonomic safety and health management, and motor vehicle safety. On August 3, 1992, OSHA published an advance notice of proposed rulemaking requesting data and comments on ergonomic hazards in the workplace related to the absence of ergonomic safety and health programs (57 *FR* 34192). In addition, OSHA has undertaken a priority compliance effort in this area. Earlier, in April 1992, OSHA rejected a petition filed by a number of labor organizations for an emergency temporary standard on ergonomics, concluding that there was no basis for emergency action. Although OSHA has stated that the publication of a proposed ergonomics standard is a high standards-setting priority, the future of the rulemaking is unclear in view of strong employer opposition and controversy in Congress over the standard.

Motor vehicle accidents constitute the single greatest cause of occupational fatalities in the country, and in July 1990, OSHA proposed a standard for occupant protection in motor vehicles (55 *FR* 28728). The standard would require employers to mandate the use of safety belts for

employee occupants of motor vehicles when on official business, and would require employer-sponsored safety awareness programs for employees. The proceeding is pending.

Standards Activity: Overview

In viewing OSHA standards activity for the years from 1987 to 1994 in retrospect, it is difficult to resist the clichéd conclusion, the more things have changed, the more they have stayed the same. The following observations, highlighting trends for the seven-year period, should be noted:

- ➢ OSHA has been confronted with increasingly sophisticated safety and health problems in the workplace, raising issues that were scarcely contemplated when the OSHAct was enacted. Among the more important of the new types of hazards are infectious diseases, specifically hepatitis-B, HIV, and tuberculosis; ergonomics hazards; and violence in the workplace. OSHA has already issued a standard on bloodborne diseases, and has promised that it would propose an ergonomics standard in the near future; however, no standards action seems near on tuberculosis or violence.
- ➢ Emergency temporary standards (ETSs) are no longer a factor in the OSHA program. Largely because of a number of court decisions vacating OSHA emergency standards on a variety of grounds, the agency now almost routinely denies petitions for ETSs. Members of the public continue to request ETSs, in order, it would seem, to add impetus to their requests and to help ensure that, at least, section 6(b) rulemaking be initiated.
- ➢ Congress has continued its involvement in the standards process. In recent years, Congress has directed the agency, by statute, to issue several specific standards, and it has even legislated timetables for their issuance. Although OSHA complies with these statutory directives, as it must, it does so at the expense of other standards priorities. As a result, the congressional action should be seen not as a measure to increase, but rather to redirect, OSHA standards activity.
- ➢ As in earlier years, all major OSHA standards, with limited exceptions, have been challenged in the courts of appeals.

The courts have continued to look closely at the substance of the standards, and although many have passed muster, in some significant instances the standards have been remanded to OSHA for further action. Significantly, in a number of important proceedings such as asbestos and formaldehyde, the courts decided that the OSHA permissible exposure limit was insufficiently stringent, and that a lower limit should be set, if feasible. OSHA appears to have mastered the rulemaking process, and procedural issues are not often raised in standards challenges. The most significant standards decision of the period was the ruling of the Court of Appeals for the Eleventh Circuit setting aside OSHA's air contaminants standard.

- ➢ Although OSHA has recently completed a number of standards proceedings that had been pending for considerable periods of time, notably the asbestos and hazard communication standards, delays in the issuance of standards continue to be an agency problem. After 1987, the rate of standards promulgation was much improved over that during the earlier deregulatory era; however, there were many disappointments, with some standards proceedings dragging on for years, and numerous important standards priorities awaiting agency action. In light of these realities, interested parties looked to Congress and to the courts for help in triggering agency standards action, and the courts of appeals several times lost patience with OSHA and ordered the agency to take action within a specified deadline. Congress has also dealt with the matter legislatively. No solution to the standards problem has appeared on the horizon, particularly because generic rulemaking has been called into question by the failure of the major air contaminants standard effort.
- ➢ In August 1994, Assistant Secretary Joseph Dear initiated a new standards-planning process. Under the new procedures, OSHA has solicited the views of top officials in labor, industry, and academia, known as "stakeholders," in an effort to help the agency determine what workplace hazards it should first address in its standards program.
- ➢ On April 23, 1994, Linda Rosenstock, Director of the Occupational and Environmental Medicine Program at the University of Washington, was appointed to head the National Institute for Occupational Safety and Health (NIOSH), the research agency of the federal occupational safety and health program. At the same time, it was announced that NIOSH headquarters would be moved from Atlanta, Georgia, back to Washington DC.

Compliance Activity

Enforcement programs played an increasingly important role in the OSHA program in the period beginning with the administration of Assistant Secretary Pendergrass.

Civil penalties are a major component of OSHA enforcement. These penalties, imposed by the agency when an employer is found to have violated the act or OSHA standards, serve as an incentive to employers to abate hazards disclosed by OSHA inspections and, in the future, to abate hazards prior to inspection. However, it has been apparent for some time that the original statutory penalty amounts were scarcely sufficient to provide the necessary incentives to employers to undertake costly abatement measures. The need for statutory change was widely recognized and, finally, as part of the Omnibus Budget Reconciliation Act of 1990, Congress adopted a seven-fold increase in the penalties OSHA was authorized to propose for violations of the act. The statute, as amended, authorized penalties of up to $70,000 for willful and repeated violations and $7,000 for other violations, and established a $5,000 minimum penalty for willful violations.

In addition, in 1986 OSHA implemented what has come to be known as the "egregious" penalty policy. In the earliest

days of the act, OSHA adopted a compliance policy under which separate instances of the same violation would be grouped for penalty purposes; thus, if 45 machines lacked the same machine guarding, all these instances would be only one violation for purposes of imposing a penalty. However, in 1986, the agency directed its field staff to impose separate penalties for different instances of violations if the inspection disclosed flagrant and widespread violations at the workplace. The stated purpose of the new policy was to make OSHA penalties more credible rather than merely being a slap on the wrist. Originally implemented for record-keeping violations, the "egregious" policy was later applied to violations in the petrochemical and construction industries, as well as to ergonomics and other program areas in other industries. The lawfulness of the "egregious" penalty policy under the OSHAct was challenged, and the Review Commission has upheld its validity on substantive and procedural grounds.

As might be expected, as a result of the statutory changes and the new administrative policies, OSHA civil penalties have markedly increased, with OSHA, for the first time in its history, proposing penalties amounting to millions of dollars. According to agency statistics for the fiscal year ending September 30, 1992, the first full year in which OSHA used the increased maximum penalties mandated by Congress and the "egregious" penalty policy, the total amount of penalties imposed reached $116.1 million, well over the previous high of $91.7 million that was recorded for the preceding fiscal year. There were sharp increases in penalties between 1990 and 1992, both in aggregate penalties and in the average amount of penalties. From 1990 to 1992, the average penalty for serious violations tripled and appears to have risen sharply for willful violations. OSHA statistics on willful violations are less clear.

On June 14, 1994, OSHA issued a directive to field staff to increase the minimum penalty for willful serious violations to $25,000 from the prior $5,000 minimum. Assistant Secretary Dear in announcing the change said that its purpose was to make it "more difficult for those few bad actors to regard penalties as simply a cost of doing business." In November 1994, OSHA published statistics on its compliance activity for fiscal year 1994. The statistics showed that federal OSHA penalties imposed were nearly $120 million, a record level, and that the number of federal inspections increased to 42,377, more than half of which were in the construction industry. In the prior fiscal year OSHA had conducted 39,536 inspections. The rate of contested federal cases was stable, continuing at approximately 11 percent.

Another major OSHA enforcement initiative during this period was corporate-wide settlement agreements. Whereas the agency and the Office of the Solicitor in the Department of Labor always encouraged informal settlement of citations and penalties, OSHA after 1987 began to seek, in the case of national companies, settlements covering not only the facility or facilities that were the subject of the citations but all or many of the corporation's facilities on a nationwide basis. Nation-wide settlements have numerous advantages. Like single-facility settlements, they avoid the burdens of administrative and court litigation and the delays in employer abatement that necessarily result from litigation, during which abatement requirements are suspended. Corporate-wide agreements also apply to facilities that were not inspected and often include requirements for specific abatement measures that are typically not included in citations themselves, or even in Review Commission orders. In fact, specific abatement requirements included in nation-wide settlements have formed the nucleus of OSHA's voluntary abatement guidelines in the field of ergonomics, and the basis of OSHA's new process safety management standard for the petrochemical industry.

The OSHAct contains criminal penalties, but these are applicable only when a willful violation leads to the death of an employee, and they generally do not apply to corporate employees. In addition, there has been little use of these criminal sanctions at the federal level. As a result, throughout the history of OSHA there has been ongoing criticism of both OSHA and the U.S. Department of Justice, which prosecutes the criminal violations, over the lack of significant criminal enforcement in the field of occupational safety and health.

The decade of the 1980s witnessed a considerable increase at the state level in the prosecution of criminal cases involving death, injury, or illness in the workplace. In these proceedings, states would typically base their prosecutions on state general criminal laws such as the manslaughter or assault statutes. In states without approved state plans, a major legal issue arose as to whether these state prosecutions were preempted by the federal OSHA statute. The highest courts in several states have ruled that there was no preemption, and the U.S. Supreme Court has refused to hear appeals on this issue.

In the meantime, federal OSHA has taken steps to improve its criminal enforcement program. These steps include OSHA staff training in criminal investigation technique and improved criminal enforcement coordination both within the Department of Labor and with the Department of Justice. Since 1990, a significantly greater number of OSHA enforcement cases have been referred to the Department of Justice for criminal enforcement, and some of these cases have resulted in convictions and jail sentences.

In establishing inspection priorities, OSHA has continued to direct its limited inspection staff resources to businesses in which it believes the greatest hazards exist; these inspection priorities are implemented in part through special-emphasis programs. A series of chemical explosions in 1989 and 1990 that resulted in the deaths and injuries of many employees led OSHA to institute a petrochemical industry special-emphasis program (PetroSEP). In 1990 this program involved in-depth inspection activity in the industry, special training for compliance officers in chemical

industry-inspection techniques, and cooperation with the EPA, which has parallel responsibility in the chemical industry under environmental statutes.

Over the last several years, there has been a significant increase in injuries and illnesses caused by repetitive motion and other ergonomic-related factors, cutting across a wide spectrum of industries and workplaces. In 1990, OSHA, responding to this new and serious problem, established a special-emphasis enforcement program for ergonomics. This program was first directed to the red meat industry, where injuries were common and related specifically to the absence of ergonomic programs. Special program management guidelines for this industry were developed by OSHA, and in August 1990, copies of the guidelines were sent to every red meat-processing facility in the country. Simultaneously, a comprehensive nation-wide inspection program was initiated, targeting large meatpacking facilities. These inspections were conducted by teams consisting of safety, health, and ergonomics experts, joined in some cases by medical personnel. To coordinate and support these and other agency activities (such as standards development) in the ergonomics area, OSHA established a new Office of Ergonomic Support in its Technical Support Directorate.

The construction industry is one of the most hazardous, and OSHA has continued to conduct approximately one half of its federal inspections in this industry. The agency has taken several other steps to enhance its compliance efforts in construction. A new Office of Construction and Engineering was created in February 1990. One of its major responsibilities is to use its expertise to investigate construction accidents and determine their causes. The office prepared a special report analyzing construction fatalities investigated by OSHA between 1985 and 1989. The reports were used both in developing standards and in fashioning enforcement strategies. OSHA has also conducted several pilot programs to improve its targeting of construction inspections, so that inspections will be made when the greatest hazards are present. OSHA reform legislation, as well as other pending bills, would greatly expand OSHA activity in the construction area.

Workplace accidents attract public attention and have always been a matter of great concern in the OSHA program. The recent accidents in the petrochemical industry, the L'Ambiance Plaza collapse, and the fire in the poultry-processing facility in North Carolina, each resulting in many worker deaths, have underscored the importance of efforts by both federal and state OSHAs to prevent such occurrences in the future. One effort is toward better coordination of standards and enforcement activity. For example, in the development of its lift-slab construction standard, OSHA used data obtained in its investigation of the L'Ambiance Plaza accident.

OSHA has also attempted to improve the quality of its investigation of the causes of accidents, and in 1991 promulgated a directive containing detailed instructions to field staff on accident investigations. Previously, both as a matter of compassion and as an investigation technique, OSHA in April 1990 had issued instructions to field staff requiring greater involvement with families of victims of workplace accidents in agency investigations of fatal accidents. Under the directive, OSHA field staff are required to contact victims' families, to explain OSHA's investigation and enforcement procedures, to invite family members to meet with OSHA officials, and to share with them information regarding the accident. Moreover, members of OSHA staff must keep family members informed "at appropriate times" of the steps OSHA is taking in connection with the investigation and enforcement proceeding. Procedures for involvement of victims and their families in OSHA enforcement are also the subject of pending legislation. On April 1, 1994, OSHA published a final rule requiring employers to report to the agency within eight hours all employee fatalities or hospitalizations of three or more workers. Previously, the time frame for reporting was 48 hours, and reports were mandatory only for five or more hospitalizations. Because OSHA inspections are triggered by these employer reports, OSHA stated, the amended rule would result in more timely inspection of serious accidents.

In September 1994, OSHA released its new *Field Inspection Reference Manual*, previously called the *Field Operations Manual*, which contains guidance to field staff in conducting workplace inspections and issuing citations and penalties. The new manual is much shorter, down from 369 pages to 102 pages, and it gives field staff greater discretion in making enforcement decisions themselves.

State Programs

Section 18 of the OSHAct encourages states to develop their own occupational safety and health programs. If a state plan is approved by federal OSHA, the state is authorized to implement its program and to receive 50 percent of the cost of the program from federal OSHA. At the present time, 21 states and 2 territories have approved plans covering approximately 40 percent of the nation's work force. Two states, New York and Connecticut, have approved plans that cover only state and municipal employees.

In July 1987, the governor of California suspended operation of the California state plan, one of the largest in the country, because of budget constraints. While the California state plan was not being implemented, federal OSHA resumed its private-sector enforcement in California. The governor's action was challenged by a number of California groups, including environmentalists and labor unions, and state court litigation on the lawfulness of the governor's action ensued. Eventually, the issue of the continuation of the state program was placed on the ballot, and in November 1988, the voters in California passed Proposition 97, reinstituting California's state occupational safety and health enforcement. In May 1989, the California program resumed operation and federal OSHA suspended its enforcement activity.

The Michigan state plan experienced a crisis, also for budget reasons, when the governor of Michigan in 1991 proposed elimination of funding for the plan. However, after a legislative compromise, adequate funds for the state plan were appropriated, and the plan has continued operating.

On September 3, 1991, there was a major fire at a poultry-processing facility in Hamlet, North Carolina, as a result of which 25 employees died. (North Carolina's state plan was approved by OSHA in January 1983, and an operational agreement giving North Carolina sole enforcement authority in the state was in effect.) Following the incident, Secretary of Labor Lynn Martin directed OSHA to conduct a complete reevaluation of the North Carolina program, as well as an evaluation of all other state programs. On September 12, 1991, a subcommittee of the House Labor Committee conducted an oversight hearing on OSHA reform legislation, at which testimony on the North Carolina fire was presented. On October 24, OSHA terminated North Carolina's operational agreement and resumed partial federal concurrent enforcement in the state.

In January 1992, OSHA completed its evaluation of the North Carolina program and concluded that the state plan was experiencing "serious operational difficulties." The state was given 90 days to correct its deficiencies, and on April 24, 1992, OSHA issued a show-cause order giving North Carolina 45 days to demonstrate why proceedings to withdraw approval of the state plan should not be initiated. In explaining its action, OSHA said that although the state had dealt with some of the difficulties in its program, others were "addressed only by assurances," without firm commitments to timetables. On June 18, OSHA suspended further action on the withdrawal of the North Carolina state plan, concluding that additional state commitments had been received, by which the state promised to take action to correct seven major deficiencies. Representatives of the labor movement criticized this OSHA action as being "outrageous" and politically motivated.

Meanwhile, in December 1991, North Carolina proposed fines of more than $800,000 against Imperial Food Products, the employer at the poultry-processing facility. Imperial did not contest the citations and penalties, and on September 14, 1992, the owner of the then-defunct company pleaded guilty to involuntary manslaughter charges and was sentenced to prison for 20 years. This was believed to be the most stringent sentence ever imposed for a state criminal violation involving occupational safety and health.

Under section 18 of the OSHAct, states with approved plans, in order to remain as effective as the federal OSHA program, are required to impose criminal sanctions for violation of their OSHA laws. However, in states without approved plans, there is a serious legal question as to whether the federal OSHAct preempts those states from enforcing state general criminal statutes for murder, manslaughter, and assault for occupational safety and health offenses. Early state court decisions suggested that such state criminal enforcement activity was preempted by the federal statute. However, the U.S. Department of Justice ultimately expressed the view that the federal act had no preemptive effect, and three later decisions of the highest courts of Illinois, Michigan, and New York ruled that state criminal enforcement was not preempted. In the first of these, *People v. Chicago Magnet Wire Corp.*, the state supreme court of Illinois emphasized the policy considerations underlying these decisions, reasoning that if the preemption argument were accepted it would in effect "convert the [OSHA] statute, which was enacted to create a safe work environment for the nation's workers, into a grant of immunity for employers responsible for serious injuries or deaths of employees." Pending OSHA reform bills would explicitly confirm the nonpreemption of state criminal enforcement.

The U.S. Supreme Court decided an important case, *Gade v. National Solid Wastes Management Association*, in which it upheld OSHA preemption of so-called dual-purpose state statutes.

BLS Statistical Survey

The most recently published results of the survey of the Bureau of Labor Statistics (BLS) of occupational injuries and illnesses in the United States was for calendar year 1992. According to the survey, the rate of work-related injuries and illnesses in the United States increased to 8.9 cases per 100 full-time workers in 1990 from 8.4 cases per 100 full-time workers, the largest one-year increase in injuries and illnesses since the BLS survey began. Virtually all of the increase consisted of less serious cases that did not involve any lost workdays. The rate of lost workday injuries and illnesses for 1992 was the same as in 1991, 3.9 per 100 workers.

The first BLS survey was completed in 1973. In that year, the injury/illness incidence rate was 11.0 per 100 workers. Since then, the rate has fluctuated, and was 8.9 in 1992. On the other hand, the lost workday case incidence rate (the number of incidents involving lost workdays) has gone up slightly since 1973 (from 3.4 to 3.9 per 100 workers).

Although BLS also reports on occupational illnesses, it has repeatedly emphasized that because of the difficulty of collecting accurate information on illnesses resulting from long-term health hazards, as in the case of carcinogens, its statistics markedly understate the number of work-related illnesses.

The results of the 1992 BLS survey did not include the number of work-related fatalities in the totals. These are now separately calculated by BLS, and on August 10, 1994, BLS published the results of its National Census of Fatal Occupational Injuries for 1993. According to the survey, a total of 6,271 workers were killed in job-related incidents in 1993, with vehicle crashes and homicide leading all other causes. Also significant was the fact that violence in the workplace was the single largest cause of death for women on the job in 1993, accounting for 39 percent of all female job-related fatalities; 1993 was the second year for which data were produced from the BLS Census of Fatal Occupational Injuries program.

BLS includes in its statistical survey all employers who are required to maintain injury and illness records under the OSHAct. In 1990, the survey covered a sample of 250,000 establishments in private industry. Parallel data for mines and railroads are compiled by the Department of Labor's Mine Safety and Health Administration and by the Federal Railroad Administration in the U.S. Department of Transportation. BLS combines all the private-sector data into its final published statistical report. Data on injuries and illnesses in the public sector, both federal and state, are published separately.

In January 1991, a major change was made in the relationship between OSHA and the Bureau of Labor Statistics. Under a new policy, OSHA assumed responsibility for determining employer record-keeping obligations under the OSHAct. BLS will continue to conduct the annual national statistical survey of occupational injuries and illnesses as it has done in the past, which is based on the employer-maintained records. Both agencies are constituent parts of the Department of Labor and consult on occupational injury and illness issues.

Also in 1991, OSHA created a new Office of Statistics. One of its responsibilities is the revision of the regulations on employer responsibilities for keeping records on occupational injuries and illnesses. The new office also works with the agency's compliance staff in Washington DC and field staff to develop better statistics for the purpose of more effectively targeting inspections to priority workplaces.

Meanwhile, BLS, in consultation with OSHA, redesigned the national data collection system. One of the main purposes of the new system is to provide more detailed demographic and case-characteristic information on workplace injuries and illnesses. In 1987, the National Academy of Sciences of the National Research Council issued a report recommending an overhaul of the BLS statistical system. After considerable study and consultation, BLS developed a new system, known as ROSH (Redesigned Occupational Safety and Health), which was first implemented for the 1992 calendar year survey. The new survey forms were mailed out by BLS in January 1993 to 280,000 employers. BLS indicated that the revision of the survey, the first in 20 years, would provide more specific and understandable data on occupational injuries and illnesses, such as the nature of the disability and pertinent worker characteristics. In addition, the revision would save employers time in completing the survey by avoiding duplication of workers' compensation data.

Legislative Activity

Between 1970, when the OSHAct was passed, and December 1990, when legislation increased seven-fold the maximum penalties that OSHA was authorized to propose, no amendments to the OSHAct were enacted. The agency, supported mainly by labor organizations, opposed any amendments to statute, fearing that even measures purporting to strengthen the law would open the statute to a rash of changes. The labor committees of the House and Senate generally agreed with this view, and as a result the statute remained unchanged for a twenty-year period.

This does not mean that there was total satisfaction with the law or its implementation. On the contrary, during this period, particularly in the early years of OSHA, there were many complaints about agency performance. In Congress, these translated into appropriations riders prohibiting the expenditure of appropriated funds by OSHA for particular purposes. In many years, there were as many as seven appropriations riders attached to OSHA appropriations legislation. However, commencing in 1989, as its hostility to OSHA decreased, Congress began a process of deleting various riders from the appropriations bills. Currently only three appropriations riders remain:

- OSHA funds may not be spent for enforcement in a farming operation with fewer than eleven employees that does not maintain a temporary labor camp.
- Funds may not be expended to develop or enforce standards affecting recreational hunting, shooting, or fishing.
- OSHA may not conduct programmed safety inspections in firms employing ten or fewer employees that are included in an industrial category that has an occupational injury lost workday case rate below the national average.

In the closing years of the 1980s, there was increasing pressure to amend the OSHAct. The traditional opposition to any amendment activity by labor organizations came to an end, and instead, labor organizations urged that the act be strengthened. Several areas of change were assigned priority for amendment; among these were criminal enforcement, the dollar amounts of penalties, the agency program in the construction industry, the procedures for issuing standards, and criteria for standards. In November 1990, the Omnibus Budget Reconciliation Act increased maximum OSHA penalty levels seven-fold and established a minimum penalty of $5,000 for willful violations. This was the first substantive amendment in the history of OSHA.

However, even after the 1990 amendment was enacted, bills continued to be introduced in Congress to further strengthen the OSHAct. Among the most important were those relating to criminal enforcement and construction standards and enforcement. Eventually, efforts to amend the OSHAct came to center around comprehensive legislation that would reform OSHA in virtually all of its areas of activity. The Senate OSHA reform bill was introduced in August 1991 by Senators Metzenbaum and Kennedy, and the House of Representatives bill was simultaneously introduced by Chairman Ford of the House Labor Committee. Extensive hearings were held in the 102nd Congress on these bills; generally, the bills were supported by labor and opposed by industry, whereas OSHA, for the most part, took the position that any needed changes in the implementation of the act could be achieved administratively. The House bill was reported favorably by the Labor Committee in July 1992,

and the Senate bill by the Senate Committee in October 1992. Nonetheless, Congress adjourned before either bill reached the floor.

Similar but not identical legislation was introduced in both the House of Representatives and the Senate in 1993. Hearings in the 103rd Congress were held in both the House of Representatives and the Senate, but the bills again did not reach the floor of either house. With the results of the 1994 election giving the Republican party a majority in Congress, any action in the foreseeable future on OSHA reform seems highly unlikely.

Congress in recent years has become actively involved in the OSHA standards program. In a number of instances, Congress has mandated that OSHA issue an occupational safety or health standard. The congressionally required standards were for employee exposure to hazardous wastes, certification for training programs given to individuals providing emergency response, process safety management, bloodborne pathogens, hazardous labeling, and lead in construction work. Particularly noteworthy was the action by Congress in October 1992 in passing the Housing and Community Development Act, which required within 180 days of enactment that OSHA issue an "interim final lead standard" covering the construction industry. Under the law, the standard would take effect upon issuance and would be "as protective" as the working protection guidelines for identification and abatement of lead-based paint issued by the U.S. Department of Housing and Urban Development. OSHA published the interim lead standard on May 4, 1993.

During the 1987–1993 period, Congress considered other legislation that affected occupational safety and health but did not amend the OSHAct itself. In 1986, Congress passed the Superfund Amendments and Reauthorization Act (SARA), requiring OSHA to issue a hazardous waste operations standard, with a specified timetable imposed. In 1987, Congress enacted as part of the Omnibus Budget Reconciliation Act a requirement that OSHA, as part of the hazardous waste standard, also provide for the accreditation of training programs for employees who work with hazardous waste. These provisions are particularly significant because the OSHAct itself does not provide for deadlines for the issuance of final standards. Since 1987, Congress on other occasions has stipulated (or tried to stipulate), through legislation or riders, time frames for the issuance of standards; a notable example was the statute requiring OSHA to issue a process safety management standard within one year.

In October 1987, the House of Representatives approved the High Risk Occupational Disease Notification and Prevention Act. The main responsibilities under this legislation were assigned to the Department of Health and Human Services, which would identify and notify employees at increased risk of disease because of their occupational exposures to toxic chemicals. OSHA would be required to submit annual reports to Congress on its enforcement of the hazard communication standard and to investigate alleged discrimination against employees at increased risk. A parallel bill reached the Senate floor in March 1988, but attempts to limit debate through cloture failed, and the bill was ultimately withdrawn.

Enacted in 1990 by Congress, the Negotiated Rulemaking Act encourages various federal agencies, including OSHA, to utilize negotiated rulemaking procedures in developing occupational safety and health standards. Although it does not require that negotiated rulemaking be used, the law facilitates its use and establishes certain procedures that must be followed if negotiated rulemaking is used. OSHA has used negotiated rulemaking successfully once, in developing an MDA standard, and unsuccessfully on other occasions. On May 11, 1994, OSHA announced that it had established a negotiated rulemaking advisory committee to make recommendations for revision of OSHA's construction standard regulating steel erection. The committee is currently continuing its deliberations. On several other occasions, notably in the grain dust and formaldehyde proceedings, OSHA made use of the recommendations of interested parties in deciding its official action.

On November 15, 1991, after considerable debate, Congress passed the Clean Air Act Amendments of 1990. Although the law related primarily to the responsibilities of the Environmental Protection Agency, two provisions directly involved OSHA. One required OSHA, within 12 months of enactment, to issue a chemical process safety standard with certain provisions as specified by Congress. The second provision established a Chemical Safety and Hazard Investigation Board with responsibility to investigate chemical releases and required OSHA to enter into a memorandum of understanding with the board to limit duplication of activity between the two.

In the last several years, Congress has also considered so-called whistle-blower legislation. These bills would provide protection for employees who exercise their rights under federal statutes, and establish prompt procedures for the vindication of those rights. These bills have not been passed. Several specific regulatory statutes such as the OSHAct and the Fair Labor Standards Act have long-standing antireprisal provisions. Because of its experience in enforcing the OSHAct antireprisal provisions, OSHA was given responsibility for enforcing the whistle-blower provisions in three non-OSHA statutes. The most important are the Surface Transportation Assistance Act, protecting trucking employees, and the Asbestos Hazard Emergency Response Act (AHERA), protecting individuals complaining about asbestos hazards in primary and secondary schools.

A recent congressional action affecting OSHA was the Workers' Family Protection Act (§209 of Pub. L. No. 102–522), passed October 26, 1992. It deals with potential hazards to families resulting from chemicals and other substances being transported on workers' clothing and persons. The law mandates a study of the problem and regulatory action by OSHA within four years based on the study.

Occupational Safety and Health Review Commission

The OSHAct established the independent three-member Occupational Safety and Health Review Commission (OSHRC) to adjudicate citations and penalties issued by OSHA. OSHRC has had a troubled history and has often found it difficult to carry out its assigned statutory role. For a period of almost two years, in 1988 and 1989, the Review Commission lacked a quorum and was unable to decide cases. This situation resulted from delays in the presidential appointment of OSHRC members and brought about a large backlog of undecided cases. In the spring of 1990, President Bush appointed three OSHRC members: Edwin G. Foulke Jr, as chairman of the commission, and Donald G. Wiseman and Velma Montoya as members. By September 1990, after Senate action, the Commission had a full roster of members and began to decide cases on a regular basis. The commission first directed itself to the backlog of undecided cases, and in fiscal year 1991 made 86 dispositions, more than triple the number during the prior fiscal year. At the close of fiscal year 1991, 86 cases were awaiting decision at the review level, as compared with 108 at the end of the prior fiscal year.

Review Commission decisions cover a broad range of issues under the act. During the 1987–1993 period, the commission decided cases on such issues as the application of the OSHAct's general duty clause (section 5[a][1]), the right of employees to participate in the settlement of cases, the scope of medical removal protection under OSHA's lead standard, citation of employers at multiemployer worksites, and interpretation of the complex requirements of the hazard communication standard.

Because an important aspect of the Review Commission's adjudicator role is to interpret OSHA standards, the issue has arisen in court review of Review Commission decisions as to whether the court should defer to the commission's interpretation when it differs from OSHA's interpretation of the same standard. In *Martin v. Occupational Safety and Health Review Commission*, the Supreme Court ruled in 1990 that reasonable interpretations of standards by OSHA were entitled to court deference.

In September 1992, the Review Commission, after notice and comment, adopted revised procedural rules for commission administrative proceedings. These new procedures, the commission said, were designed to speed up litigation before administrative law judges and the commission. Among other changes, the rules allow for mandatory scheduling of prehearing conferences at the administrative law judge's discretion, and for the imposition of simplified procedures that cannot be unilaterally vetoed by one of the parties.

On February 23, 1994, Stuart E. Weisberg was sworn in as chair of the commission, replacing Edwin G. Foulke Jr. Mr. Weisberg, a former attorney with the National Labor Relations Board and staff member in Congress, was appointed to the commission by President Clinton, only the second commission member to be appointed by a Democratic president. Weisberg stated that he intends to emphasize prompt and even-handed decision making by the commission.

Other OSHA Activities

As in prior years, OSHA continued its efforts to coordinate its activities with those of other agencies with responsibilities related to occupational safety and health. In November 1990, OSHA and the EPA entered into a memorandum of understanding under which the two agencies established a framework for coordinating their compliance activities, for exchanging data and training, and for providing one another with technical and professional assistance. Under the agreement, OSHA and the EPA have conducted a number of joint inspections in the petrochemical industry. In July 1992, OSHA and the EPA entered into a work plan implementing the 1990 memorandum, which provided for the continuation of the joint petrochemical inspections and for joint activity to remove toxic hazards from lead-smelting facilities. As already noted, under the Clean Air Act Amendments of 1990, OSHA is required to enter into an agreement with the newly established Chemical Safety and Hazard Investigation Board to eliminate duplication in the investigation of accidental chemical releases. OSHA continues to be active on the Interagency National Response Team, which coordinates federal policies and procedures in responding to oil spills and other hazardous material releases.

In April 1990, OSHA entered into an agreement with the Employment Standards Administration in the U.S. Department of Labor, which implements various labor regulatory statutes including the Fair Labor Standards Act, for the purpose of establishing procedures for the exchange of information among the compliance personnel of the two agencies. In another significant action, following the fire in the North Carolina poultry-processing facility, OSHA and the U.S. Department of Agriculture's Food Safety and Inspection Service entered into an agreement that provided for, among other things, the training of Department of Agriculture (DOA) meat inspectors in the recognition of safety hazards and for the establishment of procedures to permit USDA inspectors to report safety hazards directly to OSHA. At an oversight hearing following the fire, members of Congress expressed concern upon learning that DOA inspectors visited the facility almost daily and yet took no action to bring observed hazards to the attention of appropriate authorities.

Under an agreement between the secretaries of labor and energy, OSHA in 1990 conducted an on-site evaluation of occupational safety and health conditions at the Department of Energy's government-owned, contractor-operated (GOCO), nuclear defense facilities. A report on the investigation was submitted by OSHA to the secretary of energy, who subsequently announced that the department would make changes in operations to implement OSHA's recommendations.

Most recently, in January 1993, the U.S. Department of Labor published a proposed rule to coordinate the inspection activity of several Department of Labor agencies with

regulatory responsibility affecting farm workers. The agencies enforcing various health, safety, housing, and wage laws applicable to farm workers are OSHA, the Employment and Training Administration, the Employment Standards Administration, and the Office of the Solicitor. Whereas OSHA standards are generally not applicable to agriculture, several specific standards do apply, including the temporary labor standard and field sanitation standards.

OSHA has also increased its participation in international occupational safety and health programs. The agency lent its expertise to help emerging democracies in Europe establish occupational safety and health programs, has participated in a number of international conferences, and has been involved in deliberations relating to the North American Free Trade Agreement (NAFTA).

Although OSHA gave major emphasis to compliance activity during this period, it has continued a number of programs encouraging voluntary compliance by employers. The most important of these are state-run, on-site, sanction-free consultation services, and OSHA's three Voluntary Protection Programs, called the Star Program, the Merit Program, and the Demonstration Program. Training and education have always been an agency priority, and OSHA devoted significant resources to the New Directions grant program and to the new Targeted Training Grant Program. The OSHA Training Institute in Des Plaines, Illinois, operates a variety of training programs for OSHA compliance personnel, state personnel, and safety and health personnel from the private sector and public agencies. In the fall of 1989, as part of its outreach program OSHA began again to publish its magazine, renamed *Job Safety and Health Quarterly*. The magazine's articles provide in-depth information on an array of agency projects. OSHA also began to publish four series of one-page information sheets, distributed to the public, on the following topics: construction accidents, ergonomic hazards, consultation, and chemical industry manufacturing hazards.

Studies and Evaluations of OSHA

Since the earliest days of the OSHA program, the agency's implementation of the act has been a subject of study and evaluation, both within the government and by outside scholars and observers. At the request of congressional committees and members of Congress, the General Accounting Office (GAO) completed numerous reports on the OSHA program. The normal procedure used by the General Accounting Office is to conduct an investigation, and then prepare a draft report, which is submitted to the affected agency for comment. The final published report includes the GAO's findings, its recommendations for action, and the agency's comments. Among a number of others, the GAO published reports on the following topics relating to OSHA: "OSHA Contracting for Rulemaking Activity" (June 1989), "Options for Improving Safety and Health in the Workplace" (August 1990), "Inspectors' Opinions On Improving OSHA Effectiveness" (November 1990), "OSHA Action Needed to Improve Compliance With Hazard Communication Standard" (November 1991), "Worksite Safety and Health Programs Show Promise" (May 1992), and "Uneven Protections Provided to Congressional Employees" (October 1992). Thus, the GAO's activity covers a broad range of topics, both evaluating what OSHA does and making proposals for legislative change.

In a 1990 major report on options for improving safety and health in the workplace, the GAO presented a number of options for administrative and legislative change. In the area of standards, for example, they suggested an expedited process of revising OSHA's 1970 start-up standards; an amendment giving the agency separate authority to require substance testing by manufacturers; and a statutory requirement that OSHA act on new information (as, for example, from NIOSH) and give public explanations for its decisions to take particular courses of action. In order to enhance the deterrent effect of enforcement, the GAO proposed better administrative targeting of inspections, more inspections of hazardous worksites, an increase in the size of civil penalties, expanding criminal sanctions, and barring violators from federal contracts. GAO reports are often the basis for congressional oversight and legislative activity, and have been an important part of the development of legislative proposals for OSHA reform.

Evaluations of OSHA activity are also periodically prepared by the Department of Labor's in-house inspector general (IG). The inspector general, although part of the Labor Department, is independent of OSHA and has often criticized OSHA performance. For example, in a final report dated September 11, 1987, the inspector general found "a pattern of systemic weaknesses" in OSHA management control, construction targeting, and penalty assessment policy. The report was based on an IG investigation of OSHA's New York and Philadelphia offices. In response to the report, OSHA's Assistant Secretary Pendergrass disagreed with the IG's "sweeping" conclusions, noting that the scope of the investigation was limited to offices already identified by OSHA as having "severe problems." In April 1992, the IG commented more favorably, concluding that OSHA's "egregious" penalty was a bold step and that OSHA's settlement of "egregious" penalty cases brings about broader and more timely abatement action by employers and makes possible the collection of more penalties than would take place if the citations and penalties were litigated.

The Administrative Conference of the United States is a federal agency that studies and makes recommendations regarding the operation of federal administrative agencies. At the request of OSHA, the conference in 1986 undertook a study of the agency's operations. In 1987, law professors Sidney Shapiro and Thomas McGarity submitted a comprehensive two-phase report on OSHA. The report, largely critical of OSHA's standards activity, dealt with internal agency management and priority setting, and in the second part presented

proposals for alternative approaches to development and promulgation of standards. Based on this report, the Administrative Conference formed a set of recommendations on OSHA, first recommending administrative changes in agency operations, and then, if they do not succeed, recommending legislative change. The proposed changes include the agency use of generic standards, expedited rulemaking to update start-up standards, and renewed use of advisory committees.

Private organizations have also periodically evaluated OSHA's performance, often critically. One of the more active of these groups is the National Safe Workplace Institute, based in Chicago. In a report released on Labor Day 1988, the Institute criticized the agency's enforcement policy, including the "megafine" policy, claiming that it was a cloak for a generally weak enforcement program and that any benefits of the high penalties were offset by "sweetheart" settlement deals with large corporations.

In response, OSHA emphasized that settlements avoid the burdens of administrative and court litigation and the delays in abatement that necessarily result from litigation, during which abatement requirements are suspended. In subsequent reports issued during the administration of Assistant Secretary Scannell, the institute found less to criticize and generally offered more favorable evaluations of agency efforts.

The Bureau of National Affairs' (BNA) weekly publication, the *Occupational Safety and Health Reporter (OSHR)*, celebrated its twentieth anniversary in 1990. The publication offers a full report on OSHA news each week as well as the text of OSHA decisions, standards, and other official documents. In September 1990, it published a Special Supplement entitled, "OSHA After 20 Years: a BNA Survey of Safety and Health Professionals." The BNA, in conjunction with the American Bar Association's subcommittee on OSHA, published a major treatise entitled *Occupational Safety and Health Law* in March 1988 and a First Supplement to the treatise in March 1990. A second supplement will be published in 1995. These volumes represent a comprehensive summary of OSHA law.

Important scholarly literature on OSHA continues to be produced. Professor John E. Mendeloff, whose earlier work on OSHA standards, *Regulating Safety*, was widely recognized as a thoughtful work, in 1988 published another text on OSHA standards activity, *The Dilemma of Toxic Substance Regulation—How Overregulation Causes Underregulation*. As the title suggests, Professor Mendeloff proposed that OSHA regulate less stringently and more extensively.

In 1993, professors McGarity and Shapiro published a critical evaluation of the OSHA program entitled *Workers at Risk—The Failed Promise of the Occupational Safety and Health Administration*. The volume, which focuses on the Reagan-Bush Administrations, concludes that even when "under the leadership of professionals committed to occupational safety and health, OSHA has not risen to its potential." The book proposes some possible solutions to OSHA's problems, emphasizing programs that "give workers more power to protect themselves." In 1993, professors Wayne B. Gray and John T. Scholz published a study in *Law and Society Review* on the impact of OSHA enforcement on the workplace injury rate. Disagreeing with some of the conventional wisdom on the subject, the authors conclude that inspections resulting in penalties induced a 22 percent reduction in injury rate in the affected workplaces studied during the few years following inspection. They asserted that more pessimistic assumptions about enforcement effectiveness have resulted from "narrow deterrence perspectives."

In two other challenging studies, professor David Weil of Boston University's School of Management concluded that the presence of a union in a facility dramatically increases enforcement activity by OSHA. One study was conducted in the manufacturing sector. He found that union impact is greatest in larger facilities, where the employees are "best organized" and that, as a general matter, "if workers do not become partners in this regulatory process, the chances for OSHA success seem dim indeed." In the second study, Weil concluded that unions in the construction industry play a critical role in directing the agency's attention to union job sites "in a world of limited OSHA resources." The studies were published, respectively, in two journals, *Industrial Relations* and the *Journal of Labor Research*.

1995 TO THE YEAR 2000—OSHA BEGINS ITS SECOND 25 YEARS

Overview

As OSHA began its second 25 years of existence, the Republican Party took control of Congress in January 1995. Bill Clinton, a Democrat, was President and, although the Republicans retained control of Congress, in 1996 he was reelected. With the federal government split, the OSHA program struggled to maintain its momentum. Congress did not succeed in enacting major "reform" legislation which would have moved the agency away from a strategy emphasizing enforcement to greater reliance on a voluntary compliance program. At the same time, OSHA achieved several real advances in the areas of standards and compliance activity.

Only two relatively limited bills amending the OSHAct were enacted into law. More radical regulatory "reform" legislation failed, except for the "Contract with America" Act, enacted in 1996, which applied to all administrative agency regulation. Congressional efforts to control standards priorities were directed primarily to ergonomics, and OSHA's intention to issue an ergonomics standard was delayed for several years because of congressional appropriation riders. A proposed standard was finally issued in November 1999, but congressional efforts to delay the final standard are continuing.

OSHA standards activity has long been burdened by delays. During the five year period covered, the agency could point to a number of accomplishments in the standards area: final completion of the lead and asbestos litigation, broad revisions of the standards on respirators, longshoring, and

scaffolding in construction, and new, stronger standards on butadiene and methylene chloride. While most of these proceedings were lengthy, some extremely lengthy, the outcomes were mostly successful, with a favorable court of appeals decision on the respirator standard and, significantly, no challenges, or settled challenges, against other major standards. OSHA used the Negotiated Rulemaking Act for the first time and, more informally, settled a number of standards litigation cases by agreements with challenging parties implemented by modifications in the standard involved or interpretation.

On the other hand, OSHA has taken no final action on some important standards. OSHA discontinued work on two standards that had involved major efforts—the motor vehicle standard and the indoor air standard—and some standards, such as the standard governing tuberculosis, await final action. No proposal has been issued for the standard on hexavalent chromium.

In two cases, courts of appeals sharply set OSHA back on significant initiatives. The Cooperative Compliance Program (CCP) was held invalid by the Court of Appeals for the District of Columbia Circuit and OSHA's "per-employee" citation policy as applied in "general duty" cases were held contrary to the Act by the Court of Appeals for the Fifth Circuit. The CCP decision was noteworthy because it was based on OSHA's failure to follow proper notice-and-comment procedures in establishing the program. This ruling echoes a number of court decisions in the standards area, particularly during the 1970s, which were based on OSHA's failure to follow proper public participation procedures.

The statistics on workplace injuries, illnesses, and fatalities, assembled by the Bureau of Labor Statistics as part of its annual survey, show improvement in all areas, with rates in most cases lower than at any time since the surveys began. The BLS survey is based on employer record keeping and reporting, and a proposed comprehensive revision of these record keeping and reporting requirements was issued in 1996 and is still pending. Meanwhile, OSHA has issued a regulation authorizing OSHA itself to collect employer injury and illness data. The information is being used by OSHA as a basis for its site-specific targeting program. Despite some criticism, OSHA's long-standing multiemployer worksite citation policy was reaffirmed by the agency. And after considerable uncertainty, OSHA has proposed a standard making clear that with very limited exceptions employers must pay for employee personal protective equipment.

Finally, there was a change in the governance of OSHA. Joseph A. Dear, who had been assistant secretary to OSHA since 1993 resigned in January 1997, as President Clinton began his second term. A new Assistant Secretary was not nominated until September 1997, when the President chose Charles N. Jeffress, the Deputy Commissioner for Occupational Safety and Health in the North Carolina State Plan for the position. Jeffress was confirmed by the Senate on October 30.

Standards Activity

ERGONOMICS

OSHA's long-standing efforts to protect employees from musculoskeletal disorders (MSDs) reached an important juncture when the agency issued a proposed ergonomic standard on November 23, 1999. Numerous written comments were filed on the proposal and public hearings held in three cities, Washington DC, Chicago, and Portland, Oregon, during a nine-week period ending May 12, 2000. The hearing was reopened in Atlanta, in July 2000, to consider the economic impact of the standard on state and local governments, railroads, and the U.S. Postal Service.

In its published proposal, OSHA noted that one-third of the injuries and illnesses reported each year by the Bureau of Labor Statistics were MSDs, which are the "largest job-related injury and illness problem" in the United States today. While OSHA has received strong support from labor unions and the health community for its regulatory effort, the business community, on the other hand, has equally strongly objected to the proposed standard, and has pledged to challenge the standard in court. Among the arguments against the MSD proposal are that its requirements lack adequate scientific basis, that OSHA has seriously underestimated the cost of the standard, and that many of its requirements are vague and indefinite. In particular, the argument has been made that OSHA should await the completion of an updated study by the National Academy of the Sciences on ergonomics authorized by Congress in 1998 before taking standards action.

The most serious impediment to OSHA's MSD initiatives has been the opposition in Congress. In 1995 and again in 1998, Congress attached riders to OSHA appropriation bills precluding the expenditure of OSHA funds for the issuance of a proposed or final standard. The most recent rider, which allowed the "development" of a proposed standard, expired in fiscal year 1999, during which OSHA issued its proposed standard. However, congressional opposition to an ergonomics standard has by no means disappeared, and renewed efforts are being made to enact riders covering fiscal year 2001.

TUBERCULOSIS

Another major OSHA standard initiative was the promulgation of a proposed rule covering workplace tuberculosis hazards issued on October 17, 1997. The steady decline of tuberculosis cases reported in the United States, which began in 1953, was reversed between 1985 and 1992, after which time the number of reported cases increased by 20 percent. Employees who work in settings such as health care and correctional facilities are at a particularly high risk of occupational transmission of tuberculosis. OSHA estimated that the lifetime occupational risk of tuberculosis infection for these employees ranges between 3 to 39 cases per 1,000 workers exposed.

The development of the tuberculosis standard was initiated by the Labor Coalition to Fight TB in the Workplace,

and on August 25, 1993, the Coalition asked OSHA to initiate rulemaking under the act. While OSHA's proposed tuberculosis standard was not published until 1997, in October 1993 the agency issued a compliance directive which instructed field staff to enforce existing OSHA standards and the general duty clause, if applicable, where tuberculosis hazards were found.

The comment period on the tuberculosis proposal ended in October 1998, and was followed by public hearings on the proposal. Subsequently, the comment period was reopened twice, most recently in June 1999, to allow the public to comment on issues related to exposure to tuberculosis in homeless shelters, medical waste treatment facilities and other exposures, and to discuss new studies and data on the issue of occupational risk to tuberculosis.

As of late 2001, the standard had not yet been promulgated. Meanwhile, Congress provided funds for a one-year study by the Department of Health and Human Services of the OSHA proposal, stipulating, however, that the study was not intended to delay the promulgation of a final standard.

FINAL STANDARDS

OSHA has promulgated several final standards since 1995. One of the more important of these was the publication of final methylene chloride standard in January 1997. The new standard reduced the chemical's permissible exposure limit from 500 parts per million to 25 parts per million. The standard was challenged by an industry alliance and the United Auto Workers, but the management and labor groups subsequently jointly developed modifications to the standard and submitted a recommended amended standard to OSHA. These modifications were adopted by the agency, which published a revised final standard, containing extended compliance dates for 10 industries, on September 22, 1998. The methylene chloride standard was first proposed on November 7, 1991.

Another lengthy health standard proceeding was for 1,3-butadiene (BD). The standard was proposed on August 10, 1990 and issued as a final standard on November 4, 1996. The original Walsh–Healey BD standard was based on the then available information that BD causes irritation and narcosis. However, in 1983, a new study showed that BD causes cancer in rodents. In 1984, OSHA rejected a petition for an emergency temporary standard on BD, and after several *Federal Register* notices requesting advanced public comment, OSHA issued a proposal in 1990. Comments were received and public hearings were held in Washington DC and New Orleans in 1991. The final standard reduced the eight-hour permissible exposure limit from 1,000 parts per million to 1 part per million and provided a short-term exposure limit of 5 ppm and an action level of 0.5 ppm. The standard contains the usual health standard requirements, for example, medical surveillance, personal protective equipment, and regulated areas.

On January 8, 1998, OSHA published a final rule comprehensively amending the respirator standard, which had been adopted by the agency in 1971 as a "start-up" standard. The amended respirator standard reaffirmed OSHA's "hierarchy of controls policy," which, generally, favors engineering controls over respirators to be worn by employees as a means of meeting permissible exposure limits, but in other respects made many modifications in the requirements governing the selection and use of respirators. In particular, the amended standard required the employer to provide to the employee a "medical evaluation" before initial and annual fit-testing of employees and before required respirator use. A controversial change in the standard allowed the medical evaluation to be performed by non-physician "licensed health care professionals," to the extent allowed under state laws.

The standard was challenged by the American Iron and Steel Institute, other employer groups, the American College of Occupational and Environmental Medicine, and two associations representing nurses. The industry challenges related to several specific provisions of the standard, notably, the retention of the preference for engineering controls. The medical groups, on the other hand, challenged the provisions allowing non-physicians to perform "medical evaluations." The United Steelworkers joined in the challenge of the medical groups but otherwise supported the standard.

The Court of Appeals for the Eleventh Circuit unanimously upheld the standard. The court held the preference for engineering controls was not an issue in the rulemaking proceeding and therefore not before the court, and that the other challenged provisions were supported by substantial evidence. On the issue on nonphysicians performing "medical evaluations," the court rejected procedural arguments and ruled that substantial evidence supported this provision, in particular, evidence that licensed medical professionals "had safely and efficaciously [been] used . . . in the past for medical evaluations involving respirators." The court also noted that nonphysicians did not "automatically" qualify since, under the standard, state law ultimately determined the extent of their involvement.

Two extended important standard proceedings were finally completed by OSHA during this period. OSHA's comprehensive lead standard, issued in 1978, was upheld by the Court of Appeals for the District of Columbia in August 1980; the court, however, remanded to OSHA to determine feasibility questions respecting various industry sectors. In a later decision the court upheld OSHA's determinations on feasibility for all industry sectors except for brass and ingot manufacturing. On October 11, 1995, OSHA, based on an agreement with the involved industries, found that it would be economically feasible for those two industries to meet a permissible exposure limit of 75 micrograms of lead per cubic meter of air ($\mu g/m^3$) within six years by means of engineering and work-practice controls. (The original permissible limit was 50 $\mu g/m^3$.) The court accepted OSHA's finding in 1997, thus completing this almost 20-year proceeding.

OSHA's amended comprehensive asbestos standard covering general industry and construction, and a new asbestos standard on asbestos hazards in the shipyard industry, were issued on August 10, 1994. The most significant change was the reduction in the permissible limit from 0.2 fibers of asbestos per cubic centimeter of air to 0.1 (f/cc). Industry groups and two unions challenged the new standard. However, between 1994 and 1997, the various challenging groups withdrew their objections, in some cases after OSHA agreed to make changes in the standard, and the case did not reach court decision. Among the groups challenging the standard were the Safe Building Alliance, representing building owners, American Iron and Steel Institute, Asbestos Information Institute/North America, and AFL–CIO's Building and Construction Trades Department.

One of the novel issues raised during this litigation was whether OSHA could legally make modifications in a final rule without additional notice and comment in order to settle pending litigation. When the agency amended the asbestos standard under agreements with roofing contractors and building owners, it explained that notice-and-comment were unnecessary because the corrections were "based on the existing rulemaking record" and were "not intended to affect the protection afforded by the standard in a significant way."Although the Building and Construction Trades Department challenged these changes on the grounds that OSHA had violated the notice-and-comment requirements of the OSHAct and the Administrative Procedure Act, it later withdrew its objections and the issue was never resolved by a court.

This long-running litigation was ended in March 1998 when the court of appeals dismissed the last two pending asbestos cases pursuant to settlements with OSHA. In the meantime, in July 1997, the Court of Appeals for the Fifth Circuit vacated a portion of the asbestos shipyard and construction standard applicable to asphalt roof coatings and asbestos sealants. Concluding that there was no evidence in the record that asbestos fibers can escape from roofing sealants and become airborne and therefore no evidence that they present a hazard to employees, the court found that substantial evidence did not support the provision.

PENDING HEALTH STANDARDS

OSHA has taken no further action on its proposed rule addressing air quality in indoor work environments. A proposed standard on the subject was issued in April 1994, and public hearings on the proposed standard, which were completed in March 1995, developed the largest rulemaking record in OSHA history. A public interest group, Action for Smoking and Health (ASH), which has been pressing OSHA to regulate second-hand smoke for many years and had brought previous court actions against OSHA on the issue, returned to the court of appeals after the hearing, arguing that OSHA had failed to comply with its "Cancer Policy" timetable by not issuing an environmental tobacco smoke standard within 120 days of the close of the hearing. The court in November 1996 rejected ASH's arguments, holding that OSHA's self-imposed deadlines were "aspirational" only. ASH asked the full court of appeals to rehear the case, and although the request was denied, Judge Patricia Wald filed a separate, "troubled," opinion, stating that "if the statutory and regulatory deadlines are to mean anything," ASH was entitled to "more than an assurance" from OSHA that an air quality standard remains "one of the agency's highest priorities." OSHA's semiannual Regulatory Agenda of April 24, 2000, indicated that the "next action [is] undetermined" for the indoor air standard.

In July 1993, the Oil and Chemical Workers Union and the Health Research Group petitioned OSHA to promulgate an emergency temporary standard for hexavalent chromium lowering the permissible limit from 100 micrograms to 0.5 micrograms. The petition was based on evidence that chromium causes lung cancer and that approximately 1 million employees are regularly exposed to the substance. OSHA rejected the petition, promising that it would initiate rulemaking on the substance. Several years later, no rulemaking having begun, the Union brought suit in Court of Appeals for the Third Circuit, claiming that OSHA's continued failure to initiate chromium rulemaking constituted agency action was action "unreasonably delayed" and seeking a court order requiring agency action. The court, while agreeing that it had jurisdiction to rule on OSHA failure to act, refused to "intrude into the quintessential discretion" of OSHA to allocate resources and set priorities in deciding what rulemakings to undertake. In addition, the court noted that various "unanticipated factors," such as new studies on chromium, the 1994 election, and the U.S. Government shutdown, had compelled OSHA to reorder its standards priorities and further delayed the chromium proposal. The court noted that OSHA anticipated a chromium proposal by September 1999. As of December 2001, the chromium question still remains in the prolonged rulemaking stage.

On July 7, 1992, the court of appeals vacated the entire OSHA air contaminants standard on the ground that the rulemaking record did not establish, as to each regulated substance, that a significant risk existed and that the new exposure limit was feasible. As a result, OSHA's far-reaching effort to modify the hundreds of permissible limits issued in 1971, which were based on outdated research data, was discontinued. Since then, the agency has studied various approaches to achieve the updating of its air contaminant standard that would not be legally vulnerable under the court of appeals decision. The agency has announced that its current approach is to select, on the basis of its developed priority system, a limited number of substances for regulatory action, and then use "state of the art" risk assessments and "extensive" feasibility determinatives in developing permissible units for these specific substances. According to OSHA's most recent regulatory analysis, the agency has decided to propose new permissible limits for four chemi-

cals: carbon disulfide, glutaraldehyde, hydrazine, and trimellitic anhydride. In setting forth this plan of action, OSHA noted that it had rejected the alternative of proceeding through "nonmandatory guidelines" on the ground that the current levels were "so out of date" and overexposure was so pervasive that only an enforceable regulatory approach would achieve the necessary level of protection.

In 1998, OSHA published a Request for Information on the incidence of needlestick and sharps injuries among workers in various health care industries. According to the agency, a worker receiving such injuries from contaminated needlesticks and sharps may contract deadly diseases such as AIDS, hepatitis B, and hepatitis C. In information received in response, it was estimated that there are almost 600,000 contaminated needlestick and sharps injuries every year. OSHA issued a revised Bloodborne Pathogens Standard in January 2001 (effective April 2001) that said, among other items that where feasible, safer medical devices must be used; in addition, OSHA has revised its field instructions on enforcement of the bloodborne pathogen standard to clarify how compliance officers should cite employers that fail to use engineering and work practice controls to meet the standards requirements. Fifteen states have passed needlestick protection laws, the most recent, Ohio, Oklahoma, New Hampshire, and Maryland.

SAFETY STANDARDS

OSHA's confined spaces final standard was published on January 14, 1993. The standard included provisions regulating "permit-required confined spaces,"defined as those posing special dangers to employees because their "configurations hamper efforts to protect entrants from serious hazards." On December 1, 1998, OSHA amended the permit-required provisions of its earlier standard by providing for enhanced employee participation in the employer's permit-space program, specifically, requiring that permit-space entrants or their representatives be allowed to witness any testing or monitoring of permit spaces, and to strengthen the requirements for employer plans for the timely rescue of incapacitated permit space entrants.

One of OSHA's "start-up" safety standards adopted in 1971 governed powered industrial trucks. Among its provisions was training requirements for operators. On December 1, 1998, OSHA amended and strengthened the existing operator training requirements which are applicable to all industries, including construction and maritime, in which powered industrial trucks are used. The training requirements included, in addition to initial training, refresher training which must be given in certain specified circumstances. In addition, evaluations of each operator's performance is required as part of the initial and refresher training and at least once every three years.

In November 1996, OSHA issued proposed amendments to its "start-up" standards covering scaffolding used in construction. These standards were included in Subpart L of OSHA's Part 1926 construction safety standards. After receiving extensive public comment, holding public hearings, and twice reopening the record, OSHA issued a final scaffolding rule on August 30, 1996. The amendments, among other things, address types of scaffolding not covered by the original standard; contain provisions strengthening protection for employees using scaffolding; and extending protection to erectors and dismantlers of scaffolds, to the extent feasible. In addition, the final standard notes that it provides "greater flexibility" to employers in the use of scaffolding fall protection systems.

OSHA's longshoring standards were adopted as "start-up" standards from the Longshore and Harbor Workers' Compensation Act in 1971. The first comprehensive revision of these standards were promulgated by OSHA on July 25, 1997. According to OSHA, the amendments "essentially rewrote" the original standards, and, in addition, made parallel amendments in the marine terminal standard to provide consistency with the provisions of the longshoring standard. The changes were designed in large part "to keep them current with evolving work practices" and to address injuries and fatalities associated with cargo lifting gear, transfer and vehicular cargo, manual cargo handling, and hazardous atmospheres. In addition, the standard covers "sophisticated" cargo handling methods, such as intermodalism and specialized operations including containerized cargo, logging, and roll-on/roll-off (Ro-Ro) operations. These provisions, OSHA said, reflect the fact that the original longshoring standards were designed for activities using methods and equipment that have been "overshadowed or replaced" by "more modern" methods of cargo handling. The rulemaking was initiated by a proposal issued in June 1994, followed by public comment and hearings in three cities.

In October 1994, OSHA issued a final rule governing logging operations. The standard was challenged in the Court of Appeals for the Seventh Circuit by the Equipment Manufacturers Institute; the litigation was settled by agreement with OSHA on July 14, 1995. The settlement includes clarification of various provisions of the standard, establishes "lead times" for design changes in compliance with the standard, and allows much of the equipment meeting national consensus standard requirements to remain in use.

In promulgating a final standard covering personal protective equipment for eyes, face, hands, and feet in April 1994, OSHA did not directly address the question of whether employers must pay for the personal protective equipment (PPE) that employees are required to wear. Several months after the issuance of the standard, OSHA issued a staff memorandum interpreting all PPE specific standards as requiring employers to pay for personal personnel equipment required of employees. The only exception to that policy was for personal protective equipment, such as safety shoes and non-specialty safety glasses, that are personal in nature and often used away from the workplace. The inter-

pretation was reaffirmed in April 1995, by a "letter of interpretation" issued by the agency. However, on October 16, 1997, in *Secretary of Labor v. Union Tank Car Co.*, the Occupational Safety and Health Review Commission refused to accept the OSHA interpretation and ruled that where a standard states only that an employer must "provide" personal protective equipment, it does not mean "pay for" the equipment. The review commission accordingly dismissed an OSHA citation based on an employer's failure to provide, i.e., pay, for the protective equipment.

OSHA did not appeal the commission's ruling. However, on March 30, 1999, OSHA issued a proposed standard clarifying that under its safety, health, maritime, and construction standards, with the limited exceptions below, the employer is responsible for paying for the personal protective equipment provided. The three exceptions are safety-shoe protective footwear, prescription safety eyewear, and logging boots. OSHA has estimated that the new requirements would shift to employers annualized costs of less than $62 million across all industrial sectors. Hearings on the proposed standards were completed on August 13, 1999.

In 1992, OSHA decided, in light of the significant number of steel erection fatalities and criticism of its existing rules covering hazards in that industry, that it would utilize the negotiated rulemaking process to revise the steel erection requirements. An advisory committee was formed in 1994. The committee made its recommendations to OSHA in July 1997, and the proposed new steel erection standard, based on the committee recommendations, was published on August 13, 1998. This was the first OSHA proposal developed under the Negotiated Rulemaking Act of 1990. A public hearing was held on the proposal in December 1998. The Advisory Committee which developed the proposal consisted of members representing the U.S. Government (OSHA, NIOSH, and U.S. Corps of Engineers), labor organizations and employer construction associations. According to OSHA, the proposal will affect 39,000 steel erection employees and cost approximately $49 million each year.

A significant hazard that OSHA has begun to address is workplace violence. On April 28, 1998, the agency issued "Recommendations for Workplace Violence Prevention Programs in Late-Night Retail Establishments." As "Background" to the recommendations OSHA cited statistics showing the seriousness of the violence hazard. Thus, for example, BLS statistics showed that homicide was the second leading cause of death to workers in 1996 and accounted for 15 percent of the work fatalities in the United States. Similar statistics were provided by the U.S. Department of Justice National Crime Victimization Survey, which reported that from 1987 to 1992 almost one million persons annually were victims of violent crime at work. The agency pointed out that many incidents "can be anticipated and avoided" and "appropriate response" can prevent escalation when an incident occurs. The recommendations include elements of a prevention program which include identifying the potential risks at the workplace, hazard prevention and control, including engineering, administrative and work practice controls, training and education of staff, and evaluation of existing programs and record keeping.

In July 1990, OSHA proposed a motor vehicle safety standard. Hearings on the proposal were held in 1991, but OSHA has taken no further action on the standard.

STANDARDS PROCEDURE

The length and complexity of OSHA rulemaking proceedings has been an issue for the agency almost from the beginning of its existence. The issue has been studied extensively and numerous proposals have been offered to improve OSHA's standards operations. However, not all studies of the OSHA standards process have resulted in negative criticism. Thus, in October 1995, the Federal Office of Technology Assessment (an agency which has since been abolished) concluded that the agency's regulatory development process is, on the whole, "a coherent and credible set of procedures" which provides a reasonable opportunity to various groups to have input. The study was entitled "Gauging Control Technology and Regulatory Impact in Occupational Safety and Health—An Appraisal of OSHA's Analytic Approach," and its conclusions were based on an in-depth examination of OSHA rulemakings for five health standards—vinyl chloride, cotton dust, lead, ethylene oxide, and formaldehyde—and three safety standards—grain handling, mechanical power press operation, and powered platforms. At the same time, OSHA has itself recognized that its standards process is beset by delays, including a cumbersome and unnecessary internal review process. The National Advisory Committee on Occupational Safety and Health (NACOSH) met several times during 1999 at the request of the OSHA Assistant Secretary to review OSHA's standards development process and is planning to issue a final report and recommendations to improve the standards process and regarding steps that OSHA and NIOSH can take to better coordinate their activities. In March 2000, an OSHA official announced that the agency was moving toward a reorganization of its standard process involving the health and regulatory offices and towards a formal implementation of a "team approach" which OSHA had been utilizing for some time.

Compliance Activity

In early 1999, OSHA issued a "Directive" establishing the "OSHA High Injury/Illness Rate Targeting and Cooperative Compliance Program" (CCP). In essence, the program states that each selected employer, that is, those employers with 12,500 relatively dangerous workplaces, would be subjected to a comprehensive OSHA compliance inspection in 1999 unless the particular employer adopts a "comprehensive safety and health program" that meets the standards established in OSHA's 1989 voluntary Safety and Health Program Management Guidelines. The "Directive" was issued

by OSHA without public participation and its validity was challenged by the Chamber of Commerce, National Association of Manufacturers and employer associations on procedural and constitutional grounds. The challenge was brought in the U.S. Court of Appeals for the District of Columbia Circuit.

On April 9, 1999, a unanimous court held the Program invalid on procedural grounds. The basic underlying issue in the proceeding was whether the Directive creating the CCP was an OSHA "standard" under section 6 (b) or a regulation. If a regulation, as OSHA claimed, the court of appeals, under established precedent, had no jurisdiction over the case which should have been brought in a U.S. district court. However, if a "standard," the proceeding was properly before the court of appeals, and, unless the proceeding was exempt from public participation requirements, OSHA was required to follow the standards rule-making procedures under section 6 (b).

The court held the Directive to be a "standard." Although earlier cases had decided that, generally, an OSHA "standard" must address "a specific and already identified hazard,"the court concluded that the CCP as described in the Directive "in practical effect...obligates employers, under penalty of certain inspection to adopt [a comprehensive safety and health program], and thereby impose upon employers new safety standards more demanding" than those under the Act or under existing standards. The fact that the Directive does not address a specific hazard was held to be not "determinative." As a standard, the rule would be subject to notice-and-comment procedures (and under section 6 (b), a public hearing, if requested) unless exempt as a procedural rule or a statement of policy. The court held that the Directive was not exempt and accordingly procedurally invalid.

OSHA decided not to appeal the adverse decision to the Supreme Court. Separately, OSHA had under consideration a safety program rule which would require employers, generally, to establish safety and health programs which include workplace inspection, hazard identification, worker information and training, and control measures. (This regulation would require covered employers to implement the program; the CCP, as described, imposed no "direct" requirement on employers.) OSHA had anticipated that this safety program rule would be promulgated as a "regulation," but the court of appeals decision in the CCP case raised serious questions whether that approach was legally sound. Subsequently, an OSHA official stated that the safety program requirement, which, as noted, in 1989 had been issued as a voluntary guideline, would be issued, in mandatory form, as a "regulation" but would be designed to meet the "same legal test" as that of a standard. OSHA's most recent regulatory agenda appears to list the safety program rule as a "standard" with the date of issuance of the proposed rule "to be determined."

Under OSHA regulations, private employers are required to report to the agency workplace fatalities and multiple-hospitalization cases. Prior to 1994, the rule required reports within 48 hours, and applied only if 5 or more employees were involved in work-related hospitalization incidents. In April 1994, the rule was changed to require reports within eight hours and to cover three or more hospitalizations. In April 1995, the rule was amended further to require the same fatality and multiple-hospitalization reporting by federal agencies, mirroring the changes made the prior year in the rule applicable to private employers.

OSHA regulations, Part 1904, promulgated in 1971, impose comprehensive record-keeping and reporting requirements on covered employers. Under the regulations, employers are required to enter specified workplace injuries or illnesses on a "log," to make injury and illness records available to OSHA compliance officers during inspections, and to make reports to the Bureau of Labor Statistics (BLS) based on these statistics for purposes of BLS's Annual Survey.

However, beginning in the late 1980s a broad consensus developed among employers, unions, and experts for significant changes to simplify and otherwise improve the effectiveness and usefulness of the system. Finally on February 2, 1996, a proposed comprehensive revision of Part 1904's record-keeping and reporting requirements was published. Numerous written comments were received on the proposal and a public hearing held and it was anticipated that a final rule revising Part 1904 would be published in summer 2000. However, because the record-keeping requirements in Part 1904 were linked with OSHA's ergonomics rule, which had not yet reached final form, the agency postponed the final rule and it was issued in January 2001 with an effective date of January 2002.

In the meantime, OSHA separately published a final rule making it clear that OSHA had authority to require approximately 80,000 employers to make reports, based on their injury and illness logs, to OSHA itself. These reports, unlike those to BLS for use in the annual statistical survey, would be used by OSHA for inspection targeting purposes and to provide OSHA with information on what types of injuries and illnesses are occurring in various industry sections. Shortly before the final rule was issued, a U.S. District Court in the District of Columbia had ruled that OSHA could not "command" employers to file these reports, except as part of a compliance inspection unless it first promulgated a regulation expressly authorizing OSHA to conduct this survey. The district court decision did not deal with employer reports for the purpose of BLS's annual injury and illness survey.

In May 1991, the General Accounting Office (GAO) issued a report to Congress evaluating OSHA's procedures for determining whether employers who had been cited for violations in fact had abated the violations. GAO found deficiencies in the existing abatement verification procedures. GAO recommended that OSHA issue a regulation requiring employers to submit specific documentation that cited hazards have been abated. On March 31, 1997, after receiving public comment, OSHA amended its compliance regulations

(Part 1903) to enhance its abatement verification program. Under the new regulation, where abatement takes place during or immediately after an inspection, no further employer action is required. If the violation is other than serious or a serious violation "not requiring documentation," the employer would be required only to certify abatement through a one-page form or its equivalent. However, where the violations are "most serious," the employer must submit abatement documentation, which includes, where required, abatement plans and progress reports. The new regulation also requires the employer to notify employees of its abatement activities through posting at the workplace or by other appropriate means.

In OSHA's early history, employer citations were based on the hazard involved. Three separate instances of the same hazard would be "grouped" for penalty purposes; if 45 machines lacked the same machine guarding, this would be a single violation for penalty purposes. However, in 1986, OSHA implemented its so-called "egregious" policy, designed to make OSHA penalties more credible in situations involving flagrant or willful employer conduct or where certain aggravated factors were present. Under this policy, citations and penalties in these specific aggravated circumstances could be on a "per employee" basis; where numerous employees were exposed to the same hazard, a citation and penalty could be issued for each employee exposed. This policy was applied under OSHA's compliance directive in aggravated cases for "each instance of violation of noncompliance with OSHA record-keeping regulations, with safety and health standards, and with the General Duty Clause" (OSHA Instruction CPL 2.80). While several Review Commission cases affirmed certain applications of the "egregious" policy, the policy was rejected in the context of the general duty clause by the Court of Appeals for the Fifth Circuit in *Secretary v. Arcadian Corporation* (April 28, 1997).

In that case, 87 Arcadian employees were injured in an explosion in the employer plant. Finding no violation of a standard, OSHA cited the employer for 87 unlawful violations of the general duty clause, each with a penalty of $50,000, totaling $4,350,000. (The court of appeals noted that without applying the "egregious" policy, Arcadian would have been cited a maximum of $70,000 for a single general duty citation. In *Arcadian*, the court of appeals held that OSHA's general duty clause under traditional rules of interpretation could not be construed to support OSHA's interpretation under the "egregious policy." The court, relying on a "plain reading" of the language of the general duty clause, concluded that the thrust of the general duty clause was on "hazardous conditions" rather than on the protection of individual employees.

The *Arcadian* decision was limited to the application of per-employee penalties in general duty cases, and did not consider its validity where specific standards or regulations were involved. In an earlier case, *Hartford Roofing*, the Review Commission refused to affirm per-employee penalties for violations of the agency's perimeter roof guarding standard. The Review Commission decision suggested that the proper application of per-employee penalties would depend on the language of the specific standard involved, and OSHA has indicated that it would take this view into account in its drafting of future standards.

An example of a short-lived OSHA interpretation was the agency's statement that it would enforce the act's requirements where the workplace was an individual's home. The controversy began with a letter written by the OSHA Director of Compliance Programs in response to an employer inquiry. The employer indicated that it was moving its sales executives to home offices, each to be furnished with such equipment as desks, chairs, computers, printers, and fax machines, and asked as to the scope of its OSHA responsibilities. The OSHA response stated that in these circumstances the employer remains responsible for complying with the OSHAct because even in the home workplace "the employer retains some degree of control over the conditions." The letter added that the employer should ensure that employees are not exposed to "reasonably foreseeable hazards" and should exercise "reasonable diligence" to identify hazards in advance.

This letter, when publicized, raised a storm of criticism among employer groups and in Congress and the Assistant Secretary of OSHA was called to testify before a House oversight committee to explain, if he could, OSHA's view on home workplaces. The critics asserted that OSHA was overreaching in enforcing the act, infringing upon the privacy of homes, and issuing legal interpretations without first allowing public comment. The letter of interpretation was rescinded by the Secretary of Labor herself on January 5, 2000, in the face of congressional threats to block funds for any OSHA enforcement in home offices. Eventually, on February 25, OSHA issued a policy directive (CPL–2.0.125) encompassing guidance to field staff on home offices. The directive specifically exempted home offices from OSHA inspections and stated that the agency did not expect employers to inspect the homes of their employees. If OSHA receives a complaint on a home office hazard, it may decide to informally advise the employer of the complaint but it would not "follow-up with the employer or employee." The only exception to the policy are "home manufacturing operations threatening physical harm or posing an imminent danger."

As discussed earlier, in 1996, OSHA began to assemble injury and illness data for specific work sites. The purpose was to assist the agency to target its inspection activity more effectively. (As noted, OSHA's authority to receive these reports from employers was confirmed in a final rule, which it issued in 1999.) Initially, the agency used information from these injury and illness reports to establish its Cooperative Compliance Program (CCP), under which the 12,5000 most dangerous work sites could be targeted for inspection

unless the particular employer adopted a "comprehensive safety and health program" meeting OSHA's 1989 voluntary standards. When the CCP program was invalidated by the DC Court of Appeals, OSHA substituted a site-specific targeting inspection plan. This plan, announced on April 19, 1999, targeted for inspection during that year 2,200 work sites that have lost workday injury and illness rates above the national average, as identified in BLS's 1998 survey of workplace injuries and illnesses. The 1998 survey included 80,000 employers in specified standard Industrial Classification Codes. As explained by OSHA, the site-specific program differed from CCP in that under the site-specific programs designated employers definitely would be inspected and would not have the option of avoiding inspection by adopting a voluntary program. The court of appeals decision dealt with the coercive effect of the option available to employers to adopt a voluntary compliance program and did not address OSHA's authority to decide on its inspection priorities.

OSHA has indicated that in the year 2000 it hoped that funds will be available to allow it to inspect 4,200 work sites under the site-specific targeting program.

OSHA's so-called "multiemployer" citation policy was issued in the 1970s. Its genesis was in the construction industry, where numerous employers are engaged in operations and the employer who has control over a hazard does not necessarily employ those employees who are exposed to the hazard. The OSHA multiemployer citation policy was recently reaffirmed in its essential principles in a new policy directive, effective December 10, 1999. Essentially, an employer who "creates" a hazard or controls the worksite may be cited for violation of the act "even if the only employees exposed are those of other employers at the site." Similarly, under the policy, the employer who employs exposed employees would be subject to citation, even though it did not create or control the hazard if it knew or should have known of the hazard and failed to protect its employees.

While the policy has been upheld in a number of court decisions, most recently by the Court of Appeals for the Tenth Circuit in *Universal Construction Co. Inc. v. OSHRC* (6/28/99), the policy has been criticized, particularly by representatives of general contractors claiming that they have been held responsible for the safety of employees who are employed and controlled by other employers. One appellate court, the Court of Appeals for the District of Columbia Circuit, in a June 1999 decision in *IBP Inc. v. Secretary* (6/2/98), refused in a nonconstruction context to hold a general contractor responsible for another subcontractor's employees exposed to a hazard solely because the general contractor had the power to terminate the contract of the subcontractor. This, the court said, would be "to employ a howitzer to hit a small target" by bringing plant operations to a close. Moreover, the court concluded that the policy would be a disincentive to the general contractor to improve safety since the general contractor would prefer to remove references to safety in its contract rather than remove subcontractors from the plant.

In its December 1999 directive reaffirming the multiemployer citations policy, OSHA gave additional guidance to compliance staff for applying the policy in specific situations. Thus, the directive explains the factual circumstances which could appropriately support a finding that an employer is a "creating" employer ("created the hazard") or an "exposing" employer ("exposed its employees to the hazard").

Section 11(c) of the act protects an employee from employer retaliation because the employee has exercised a right under the act; examples of such rights would include filing an OSHA complaint or testifying at an OSHA hearing. The procedure for enforcing section 11(c) differs from the enforcement of OSHA standards. Under 11(c), the process starts with an employee complaint to OSHA, and if OSHA deems the complaint meritorious, it brings an action in a federal district court. In recent years, jurisdiction has been transferred to OSHA to enforce "whistleblower" provisions, similar to section 11(c), in effect under other statutes, primarily environmental protection statutes (for example, Toxic Substances Control Act).

The history of OSHA implementation of section 11(c) has long been problematic. While the agency prevailed in the only 11(c) case that reached the U.S. Supreme Court, *Whirlpool v. Marshall,* in the courts of appeals the record is mixed, with the agency sometimes failing to meet its burden in establishing that a discharge was "because" of protected activity or that the particular activity was "protected" by section 11(c). Further, OSHA has been criticized for delays in handling section 11(c) complaints and in failing adequately to publicize the program. In March 1997, the Department of Labor's Inspector General called on OSHA to work more closely with the Office of the Solicitor in taking "aggressive"measures to ensure that employees discriminated against would receive an adequate remedy. Several months later, a "whistleblower" task force was formed and on July 1, 1998, its report was forwarded to NACOSH. Among its major recommendations were that OSHA should seek punitive damages against the employer in aggravated cases, that additional resources be provided to the program, and, importantly, that greater publicity be given to the program, particularly so that where an employee was the victim of retaliation, fellow-employees should become aware when a remedy has been won either by court decision or settlement. Otherwise, there would be a "chilling effect" on workers who would believe that discrimination is taking place and OSHA is taking no action. The Task Force also recommended legislative action, including an amendment transferring OSHA 11(c) jurisdiction from the district courts to the Review Commission.

No 11(c) legislation has progressed in Congress.

While the U.S. Supreme Court did not issue any decisions on OSHA since 1995, it remanded an OSHA case to the court of appeals which, on the basis of Supreme Court precedent, reversed its earlier decision dismissing OSHA citations.

In *S.A. Healey v. OSHRC*, a methane explosion at the employer's plant resulted in the death of three employees. OSHA cited the employer for 68 violations, but the administrative proceeding was stayed while the employer was prosecuted for criminal violation by the U.S. Department of Justice. After the employer was criminally convicted, OSHA proceeded with the citation proceedings, but the Seventh Circuit of Appeals dismissed the citation, citing the constitutional principle prohibiting "double jeopardy." However, when the Supreme Court in a different case held that "double jeopardy" did not apply where a civil sanction was following a criminal sanction unless there was the "clearest proof that the [civil] penalty is really criminal," the court of appeals reversed itself and held that OSHA's administrative penalties were in reality civil and not criminal and affirmed OSHA's citations and penalties.

OSHA releases periodic statistics on its enforcement activity. In Fiscal Year 1999, OSHA conducted 37,165 inspections, it imposed slightly more than $90 million in penalties, and issued 77,196 total violations, 646 willful violations, and 50,567 serious violations. The contest rate was 9.9 percent. Numerical comparisons with prior years may be misleading, however, because so many factors, not always apparent, are involved in compliance activity. The number of inspections, however, has been more or less stable since 1990 (around 40,000 a year), but down from highs in earlier years. For example, OSHA conducted more than 81,000 inspections in 1975 and more than 71,000 in 1984 and 1985. Similarly, the contest rate has been stable, around 10 percent, in the last ten years, up from a low of 2.8 percent in 1985, but considerably lower than the high of more than 20 percent in 1979 and 1980.

Another statistical measure of OSHA performance is the BLS annual survey of injuries and illnesses. According to the BLS statistical report released in December 1999, the total injury and illness incidence rate in 1998 continued a six-year trend of decline. The rate was 7.1 injuries and illnesses per 100 workers in 1994 and 6.7 in 1998. The rate in 1994 was 8.4 per 100 full-time workers, and in 1973, the first year of the survey, the rate was at a high of 11.0 per 100 workers. BLS also reported that the number of workplace illnesses declined from 430,000 new cases in 1997 to 392,000 in 1998. Other declines in rates noted by BLS were 3.1 lost workday injury and illness cases per 100 workers and 3.5 non-lost workday injury and illness cases per 100 workers, both the lowest rates recorded in BLS surveys.

In April 2000, BLS presented additional statistics: the number of lost-workday injury and illness cases in 1998 continued to decline, from 2.3 million in 1992 to 1.7 million in 1998. The April report also indicated that the number of lost-workday musculoskeletal cases during 1998 was nearly 593,000. While the number of carpal tunnel syndrome cases went down from 41,000 in 1993 to 26,300 in 1998, cases related to repetitive motion resulted in the longest absences from work among the leading kinds of exposures, a median of 15 lost workdays. In an earlier report in August 1999, BLS said that total work-related fatalities in 1998 totaled 6,026, the lowest number since the survey began. According to BLS, this reduction was largely due to an 18 percent drop in job-related homicides from 1997. A total of 709 homicides occurred on-the-job in 1998, the lowest total for the past seven years. On the other hand, work-related deaths from highway crashes increased by 3 percent in 1998, from 1,393 in 1997 to 1,431 in 1998; more than 40 percent of those killed in highway accidents in 1998 were truck drivers.

Legislative Activity

When the Republican party gained a majority in both the House of Representatives and the Senate as a result of the 1994 election, the relationship between OSHA and the Congress, not unexpectedly, went through a significant change. Members of Congress embarked on a major effort, which continued for several years, to achieve what has come to be known as "regulatory reform." This, of course, means many different things, but, in essence, it encompasses the twin objectives of lessening regulatory burdens and improving the regulatory process. Some of the laws sought to be enacted were generic, that is, applicable broadly to all or almost all regulatory agencies. In addition, OSHA, a traditional target for reform, was the subject of agency-specific legislative activity. Ultimately, two relatively modest statutes were enacted respecting OSHA. However, much of the Congressional effort on OSHA was devoted to appropriations riders to prevent OSHA from issuing, or in some cases, from enforcing, a particular occupational safety or health standard. These efforts were successful temporarily only regarding OSHA's proposed ergonomics standard, and they were continuing into 2000, as OSHA nears promised promulgation of a final ergonomics standard.

The major regulatory reform action of Congress was taken in 1996 with the enactment of the Contract with America Advancement Act (P.L. 104–121). Title II of the act provided a statutory mechanism for Congressional review of administrative agency rules. In the *Chadha* case in 1984, the U.S. Supreme Court had invalidated on constitutional grounds the one-house legislative veto. Under the new statute, Congress is given 60 days to review agency rules, after which Congress may enact legislation canceling the rule. Title II differed from the law held unconstitutional in that it requires legislative action—two Houses of Congress and submission to the President—before a rule is canceled. However, the new review mechanism has never been invoked as to an OSHA rule and, indeed, has rarely if ever been invoked as to any rule. As will be discussed, Congress has preferred to block an "objectionable" rule before it is issued rather than cancel the rule after issuance.

The Contract with America Act also significantly expanded the procedural requirements to be followed by Agencies before regulating "small entities." The provi-

sions—called the "Small Business Regulatory Enforcement Fairness Act"—also authorize for the first time judicial review of whether an agency has complied with the Regulatory Flexibility Act, which requires Agencies to assess the potential impact of regulations on small entities. OSHA and EPA are the two federal agencies most affected by the small business regulatory amendments, but the impact of the requirements on the regulatory process and on the regulation of small employers is not entirely clear.

Many other generic regulatory reform bills were actively considered by Congress during this period but were not enacted. The most significant of these, sponsored by former Senator Dole and others, failed in July 1995 when the Senate twice preferred to end debate on the bill by a cloture vote. The bill, generally, would have required cost-benefit analysis and risk assessments for major regulations, would require agencies to adopt the least costly regulations, and would enhance the opportunity for court challenges to agency regulations by members of the public. Numerous other bills directed specifically to OSHA were considered by the Republican Congress, most extensively in the 104th Congress. As an example, a bill not enacted introduced by Cass Ballenger, then Chairperson of the House Economic and Educational Opportunities Subcommittee on Workforce Protections, would have overhauled the structure and functioning of OSHA. In addition to merging OSHA and the Mine Safety and Health Administration, the bill would have dramatically changed the process for promulgating and enforcing OSHA standards. Thus, among many other provisions, the bill would have required a cost-benefit analysis not only for new standards but also, within seven years, for existing standards; it would also provide a 30-day safe harbor before an employer would be cited or penalized; and would exempt small employers.

Although the radical reform legislation did not pass, two OSHA bills received Congressional endorsement and were signed by President Clinton on July 16, 1998. The first, P.L. 105–97, expressly authorizes voluntary consultation programs. Although these programs were already in existence, the law codified the program. The second bill, P.L. 105–98, sometimes referred to as the "no-quota" bill, prohibited OSHA from using the results of enforcement activities, including statistics on inspections, citations, and penalties, as performance measures for OSHA inspectors and their supervisors. The policy had also already begun being implemented by OSHA, and this legislation assures that it will not be instituted in the future.

On January 28, 1998, President Clinton signed into law the Postal Employees Safety Enhancement Act. The new law extended OSHA jurisdiction to the more than 1 million Postal Service employees and authorized OSHA to issue citations and penalties against their employer, the Postal Service. Significant protective legislation affecting government employees, the Congressional Accountability Act, was passed in 1995. Under the new statute, various labor protection laws—such as the Fair Labor Standards Act—were made applicable to legislative branch employees who previously had been exempted from statutory protection. On January 1, 1997, under the statutory provisions, the OSHAct, as well as the Americans with Disabilities Act, became applicable to congressional employees.

Major congressional attention in the OSHA area was devoted to appropriations riders. These, included in appropriations bills, preclude agency expenditures for particular purposes. As a procedural matter, they are generally easier to enact than statutes for which more elaborate procedures are necessary under congressional rules and practice. On the other hand, these riders are valid only for the life of the appropriations bill, which is the single fiscal year. However, a rider, once added to an appropriations bill, is almost routinely reenacted year after year and often becomes the equivalent of a statute. This has been the case with OSHA riders that originated in the 1970s, such as the one barring inspections of small farms.

The riders dealing with OSHA's ergonomics standard has been an active issue in each Congress since 1995. The ergonomics standard, strongly supported by the current Administration of OSHA and opposed by many Members of Congress, was the subject of appropriation riders enacted by Congress in 1995 and again in 1998. In May 1995, in the fiscal 1995 appropriations bill, Congress barred the use of appropriated funds for OSHA to issue "any proposed or final standard or guideline regarding ergonomic protection" but allowed expenditures for "risk assessment activity" or for activity "necessary" "to establish the scientific base" for an ergonomic standard or guideline. This restriction continued through fiscal year 1996, was not reenacted for fiscal year 1997, but was reenacted for fiscal year 1998. The rider was not passed in 1998, which would have been applicable to fiscal year 1999, and in 1999, OSHA promulgated its proposed ergonomics standard. Efforts in Congress to block a final ergonomics standard, which OSHA has scheduled by the end of the year 2000, have continued. In August 1999, the House of Representatives passed a bill (not a rider) prohibiting the issuance of a final ergonomics rule until 2001 when a federally funded study on ergonomics by the National Academy of Sciences is scheduled for completion. The bill did not reach the Senate floor. And, in June 2000, an "order"—technically distinct from a "rider," it was argued—prohibiting expenditures for the promulgation or enforcement of an ergonomics standard was introduced in the House Appropriations Committee. The "order" was approved in the Committee and passed by the House, and a similar rider to the OSHA appropriation was passed in the Senate on June 30. President Clinton has promised to veto the legislation for a number of reasons, including the ergonomics provision, and the future of the struggle between Congress and OSHA on the ergonomics issue remains unresolved.

Other riders not involving ergonomics were introduced in Congress at various times, but none were enacted. As an

example, in October 1999, language in the House labor appropriations bill would have barred an OSHA tuberculosis standard without a study of the subject by the National Academy of Sciences (NAS), similar to the study by NAS now underway of the ergonomics standard. The same bill would have precluded OSHA from issuing citations in certain cases involving latex gloves and would have prevented the issuance of general duty citations predicated on the agency's technical information bulletin on latex gloves.

Other Issues: Preemption

Under section 18 of the OSHAct, a state occupational safety and health standard relating to an "occupational safety and health issue with respect to which a federal standard has been promulgated" is preempted by the federal regulation unless the state standard is part of an approved state OSHA plan. This provision was interpreted by the U.S. Supreme Court in *Gade v. National Solid Wastes Mgmt. Association* (1992) (discussed earlier). On September 29, 1997, the Court of Appeals for the Ninth Circuit invalidated in *Industrial Truck Association v. Henry* certain California regulatory requirements, not part of California's approved state plan, on the ground that they were preempted by federal OSHA's Hazard Communication Standard. The California statute and regulations relevantly prohibited a person doing business in the state from exposing any person to a substance known to cause cancer, birth defects, or other reproductive harm without a "clear and reasonable warning" before exposure. The court of appeals' conclusion was based on its findings that both the California and the federal regulations "related to the same issue," that they "both directly govern occupational safety and health," and compliance with one regulation "expressly satisfies the substantive requirement of the other." The court emphasized that its ruling applied only to that part of the state regulation which had not been included in the state plan.

Of related importance in the California state program, the Court of Appeals of California, Third Appellate District, on October 29, 1999, upheld, with the exception of one notable provision, the state ergonomics standard (*Pulaski v. California Occupational Safety and Health Standards Board*). In 1993, the California Legislature passed a law directing the California OSHA Standards Board to "adopt standards for ergonomics in the workplace." Following protracted rulemaking, the Standards Board adopted an ergonomics regulation which became effective in July 1997. The standard was challenged by both industry and labor; the California trial court rejected the arguments of the employer groups but upheld most of the arguments of labor that the standard was invalid because it included various "loopholes" which violated the mandate of the authorizing statute. The California appellate court affirmed the trial court decision as to the industry arguments. However, the appellate court reversed many of the lower court findings on the alleged "loopholes" except as to the provision eliminating coverage over "small businesses," defined as those with nine or fewer employees. Observing that the breadth of the exempt is "staggering," immunizing four out of five California employers from the regulation, the court concluded that the regulation was "invalid per se" because it was inconsistent with the authorizing statute which required coverage of ergonomics hazards "in the workplace," which included "any place where work is performed."

A federal ergonomics standard is certain to be challenged in court. The California decision is likely to be cited by litigants in that proceeding, although the Federal regulation was issued under the OSHA general standard authority and not, as in California, pursuant to a statute directed specifically to ergonomics.

SUMMARY

The year 1995 marks the 25th anniversary of the OSHA program. Looking ahead, OSHA confronts an uncertain future, as the new Republican majority in Congress proclaims its intention to establish an entirely new direction for government regulation. Looking back, however, OSHA can quietly boast of many important accomplishments. These accomplishments, in such areas as enforcement, standards setting, training and education, and statistics and research, have been described in detail in this chapter. But beyond any specific accomplishments, OSHA's central significance is that it has changed the way Americans think about occupational safety and health.

Before 1970, the concept of occupational safety and health was on the fringe of the national consciousness. There were hardly any individuals or organizations that paid any particular attention to the increasingly serious safety and health hazards in the workplace and the moral and economic imperatives that demanded that workers be protected from those hazards. Because of OSHA, all this has changed. Although some admire OSHA and others harbor animosity toward the program, almost no one with any connection to America's workplaces would think of ignoring the responsibility of the community "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions" (OSHAct Section 2(b), 1970).

The recognition of this responsibility is the lasting contribution of OSHA to the forging of the American moral conscience. It will not be quickly forgotten, whatever changes in regulatory fashion may take place in the years to come.

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Additional Resources

Appendix A

Appendix

A

Additional Resources

by Deborah Gold and D.R. Iverson

The 30 years since the passage of the Occupational Safety and Health Act has seen an almost explosive broadening in the practice of industrial hygiene. Industrial hygiene practice may now include such diverse issues as the control of airborne chemical contaminants, noise, ionizing and non-ionizing radiations, ergonomics, environmental pollution, infectious and communicable diseases, safety, and indoor air quality.

It is almost impossible for any one professional to be an expert on every aspect of industrial hygiene practice. Fortunately, there are many organizations which the industrial hygienist or safety professional can turn to for help, including:

- *professional organizations*
- *scientific and service organizations*
- *governmental agencies*
- *occupational health clinics*
- *COSH and other community groups*
- *industry organizations*
- *labor unions and other employee organizations*
- *university based research and training programs*

The first part of this chapter includes some information about those types of organizations. The second part of this chapter includes information about on-line sources of information, including the Internet, and a bibliography for selected topics.

PROFESSIONAL ORGANIZATIONS

American Association of Occupational Health Nurses (AAOHN)
2920 Brandywine Rd. Suite 100
Atlanta, GA 30341
(770)455-7757, Fax (770)455-7271; www.aaohn.org

American Biological Safety Association
1202 Allanson Rd.
Mundelein, IL 60060
(847)949-1517; Fax (847)566-4580; www.absa.org.
Certifies biosafety professionals. Many areas have local chapters.

American Board of Industrial Hygiene
6015 West St. Joseph, Suite 102
Lansing, MI 48917-3980
(517)321-2638; Fax (517) 321-4624; www.abih.org
The ABIH administers a national certification program for industrial hygienists, in general practice and in several specialty areas.

American Conference of Governmental
Industrial Hygienists (ACGIH)
Kemper Woods Center
1330 Kemper Meadow Dr., Suite 600
Cincinnati, OH 45240
(513) 742-2020 Fax (513) 742-3355. www.acgih.org.
The ACGIH annually publishes Threshold Limit Values® for air contaminants, and other consensus standards, and publishes and distributes a wide range of manuals and other materials regarding industrial hygiene practice.

American Industrial Hygiene Association (AIHA)
2700 Prosperity Ave., Suite 250
Fairfax, VA 22031
(703) 849-8888 Fax (703) 207-3561.www.aiha.org.
The AIHA provides continuing education programs and opportunities for industrial hygienists to meet and exchange ideas. It also maintains a laboratory certification program. Recently the AIHA and the American Academy of Industrial Hygiene voted to merge, and the reorganization will create new committees within the AIHA.

American Public Health Association (APHA)
800 I Street NW
Washington, DC 20001
(202)777-2742 TTY 202-777-2500 Fax (202)777-2534; www.apha.org.
The Occupational Health Section of the APHA makes policy recommendations regarding occupational safety and health issues, and views industrial hygiene practice within a public health context. This section also cooperates with the Maquiladora Support Network to address issues of globalization.

American Society of Heating, Refrigerating, and
Air Conditioning Engineers (ASHRAE)
1791 Tullie Circle, NE
Atlanta, GA 30329
(800)527-4723; www.ashrae.org.
ASHRAE publishes consensus standards regarding the performance of building ventilation systems and other indoor air quality issues.

American Society of Safety Engineers
1800 E. Oakton St.
Des Plaines, IL 60018
(847)699-2929; Fax (847)768-3434; www.asse.org.

Board of Certified Safety Professionals
208 Burwash Ave.
Savoy, IL 61874
(217)359-9263; www.bcsp.org.
The Board of Certified Safety Professionals administers a national certification program, which is open to participation by industrial hygienists.

Health Physics Society
1313 Dolley Madison Blvd, Suite 402
McLean, VA 22101
(703)790-1745; Fax (703)790-2672; www.hps.org.

Human Factors and Ergonomics Society
P.O. Box 1369
Santa Monica, CA 90406-1369
(310) 394-1811 Fax (310) 394-2410; www.hfes.org.

Illuminating Engineering Society of North America
120 Wall St. Floor 17
New York, NY 10005
(212)248-5000; Fax (212)248-5017; www.iesna.org.

Society of Manufacturing Engineers
One SME Drive
Dearborn, MI 48121
(800)733-4763 or (313)271-1500; Fax (313)271-2861; www.sme.org.

Society of Toxicology
1767 Business Center Dr. Suite 302
Reston, VA 20190
(703)438-3115; Fax (703)438-3113;
www.toxicology.org.

SCIENTIFIC AND SERVICE ORGANIZATIONS

American National Standards Institute (ANSI)
1430 Broadway, 13th floor, New York, NY 10018
Phone: (212)354-3300; Fax: (212)398-0023; www.ansi.org
Publishes consensus standards on a variety of health and safety issues; many standards may now be purchased electronically on-line.

National Council on Radiation Protection and Measurements
7910 Woodmont Ave., Suite 800
Bethesda, MD 20814
(301)657-2652; Fax (301)907-8768;
www.ncrp.com

National Fire Protection Association
1 Batterymarch Park, P.O. Box 9101
Quincy, MA 02269-9101
(800) 344-3555 or (617)770-3000; Fax (617)770-0700; www.nfpa.org.
Publishes national consensus fire code and interpretive handbooks.

National Safety Council
1121 Spring Lake Dr.
Itasca, IL 60143-3201
(800)848-5588; www.nsc.org.

Underwriters Laboratories Inc.
333 Pfingsten Rd.
Northbrook, IL 60062
(847)272-8800; Fax (845)272-8129; www.ul.com
Website includes a list of testing laboratories.

U.S. GOVERNMENT AGENCIES

NIOSH

The National Institute for Occupational Safety and Health (NIOSH) was established by the Occupational Safety and Health Act of 1970. The OSHAct made NIOSH responsible for conducting research to make the nation's work places healthier and safer.

To identify hazards, NIOSH conducts inspections, laboratory and epidemiological research, publishes its findings, and makes recommendations for improved working conditions to regulatory agencies such as the Occupational Safety and Health Administration and the Mine Safety and Health Administration.

NIOSH works with groups and individuals who share its concern for protecting the health of all American workers. It plays a vital role training occupational health and safety experts and communicating the latest results to those most concerned.

All NIOSH Services can be accessed through a toll-free number: 1(800)35-NIOSH (1(800)356-4674). NIOSH can also be reached at www.cdc.gov./niosh/homepage.html.

Key NIOSH Services

HEALTH HAZARD EVALUATIONS

Employers, employees, or their representatives who suspect a health problem in the workplace can request a NIOSH Health Hazard Evaluation (HHE) to assess the problem.

MINERS' X-RAYS

NIOSH conducts surveillance on the health of miners, including early detection of coal workers' pneumoconiosis.

FATAL ACCIDENT INVESTIGATIONS

NIOSH identifies risk factors for work-related fatalities and injuries through its Fatal Accident Circumstances and Epidemiology project (FACE).

EXTRAMURAL GRANTS

NIOSH sponsors extramural research in priority areas and coordinates this with its intramural and contract research and that of other HHS and U.S. departments.

DATABASES

NIOSH maintains extensive databases of occupational safety and health information from around the world.

RESPIRATORS

NIOSH tests and certifies respirators to assure their compliance with federal requirements.

EDUCATIONAL RESEARCH CENTERS

NIOSH supports Education and Research Centers (ERCs) at U.S. universities to help assure an adequate supply of trained occupational safety and health professionals (see listing below).

PUBLICATIONS

NIOSH publishes and distributes a variety of publications related to occupational safety and health. Electronic versions of some publications are available on-line.

In addition to NIOSH, many state health departments maintain their own occupational health and safety divisions. You should contact them for more information.

OSHA

The Occupational Safety and Health Administration (OSHA) was created under the Occupational Safety and Health Act (OSHAct) of 1970, within the Department of Labor "*...to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources.*"

U.S. Department of Labor
Occupational Safety and Health Administration (OSHA)
200 Constitution Ave. NW
Washington, DC 20210
(800)321-OSHA (to report an emergency)
(202)219-8148 (for information)
Fax (202)219-5986
www.osha.gov

Regional Offices

(Please Note: In addition to OSHA, many states maintain their own federally approved occupational safety and health plans, indicated with *).

Region I
(CT*, MA, ME, NH, RI, VT*)
JFK Federal Building, Room E340
Boston, MA 02203
(617)565-9860
Fax (617)565-9827

Region II
(NJ, NY*, PR*, VI*)
201 Varick St.
Room 670
New York, NY 10014
(212)337-2378
Fax 212-337-2371

Region III
(DC, DE, MD*, PA, VA*, WV)
US Department of Labor / OSHA
The Curtis Center 170 S. Independence Mall West
Suite 740 West
Philadelphia, PA 19106-3309
(215)861-4900
Fax (215)861-4904

Region IV
(AL, FL, GA, KY*, MS, NC*, SC*, TN*)
61 Forsyth St., SW
Atlanta, GA 30303
(404)562-2300
Fax (404)562-2295

Region V
(IL, IN*, MI*, MN*, OH, WI)
230 S. Dearborn St.
Room 3244
Chicago, IL 60604
(312)353-2220
Fax (312)353-7774

Region VI
(AR, LA, NM*, OK, TX)
525 Griffin St.
Room 602
Dallas, TX 75202
(214)767-4731
Fax (214)767-4137

Region VII
(IA*, KS, MO, NE)
City Center Square
1100 Main St., Suite 800
Kansas City, MO 64105
(816)426-5861
Fax (816)426-2750

Region VIII
(CO, MT, ND, SD, UT*, WY*)
1999 Broadway, Suite 1690
Denver, CO 80202-5716
(303)844-1600
Fax (303)844-1616

Region IX
(American Samoa, AZ*, CA*, Guam, HI*, NV*)
71 Stevenson St.
Room 420
San Francisco, CA 94105
(415)975-4310 (main public 8-4:30)
(800)475-4019 (for technical assistance)
(800)475-4020 (for complaints, accidents, fatalities)
(800)475-4022 (for publications request)
Fax (415)975-4319

Region X
(AK*, ID, OR*, WA*)
1111 Third Ave., Suite 715
Seattle, WA 98101-3212
(206)553-5930

* These states and territories operate their own OSHA-approved job safety and health programs (the Connecticut and New York plans cover public employees only). States with approved programs must have a standard that is identical to, or at least as effective as, the federal standard.

ASSOCIATION OF OCCUPATIONAL AND ENVIRONMENTAL CLINICS (AOEC)

The Association of Occupational and Environmental Clinics (AOEC) is a network of over 60 clinics in the United States and Canada. Their purpose is to evaluate and treat patients with occupational and environmental exposures. All of the following clinics may be accessed in more detail via the Internet at www.aoec.org.

Alabama

University of Alabama at Birmingham
2151 Highland Ave. #250
Birmingham, AL 35205
(205)933-5300
Matthew Reardon, MD, MPH

Arizona

Samaritan Occupational and Environmental Toxicology Clinic
Department of Medical Toxicology
925 E. McDowell Rd., Second Floor
Phoenix, AZ 85006
(602)239-2371
Fax (602)239-6228
Kevin Wallace, MD

California

Occupational and Environmental Medicine Clinic
University of California at San Francisco/SFGH
Building 30, 5th Floor, 1001 Potrero Ave.
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2380 Sutter St, 3rd fl
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Sacramento, CA 95817
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Center for Occupational and Environmental Health
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Colorado

Division of Environmental and Occupational Health Sciences
National Jewish Medical Research Center
1400 Jackson St.
Denver, CO 80206
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Fax (303)398-1452
Appts (303)398-1733
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Alt. Contact Cecile Rose, MD, MPH

Toxicology Associates
2555 S. Downing St., #260
Denver, CO 80210
(303)765-3800
Fax (303)765-3804
Scott Phillips, MD, FACP

Connecticut

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135 College St., 3rd Floor
New Haven, CT 06510
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Fax (203)785-7391
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Occupational and Environmental Medicine Program
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Northwest Connecticut Occupational Medical Center
333 Kennedy Drive, Suite 202
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Fax (860)489-4647
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District of Columbia

Division of Occupational and Environmental Medicine
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Section of Occupational and Environmental Medicine
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Georgia

Environmental and Occupational Medicine Consultative Clinic
The Emory Clinic
1525 Clifton Rd., NE, Rm. 404
Atlanta, GA 30322
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Fax (404)727-8744
Fred Cerr, MD

Illinois

Occupational Medicine Clinic
Cook County Hospital
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Chicago, IL 60612
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Iowa

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Department of Internal Medicine - College of Medicine
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University of Kentucky Occupational Medicine Program
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Louisiana

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Caritas Good Samaritan Occupational Health Services
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75 Stockwell Dr.
Avon, MA 02332
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Fax (508)427-3905
Robert Naparstek, MD

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Massachusetts Respiratory Hospital
2001 Washington St.
South Braintree, MA 02184
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Fax (781)843-5445
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Occupational Health Program
Department of Family and Community Medicine
University of Massachusetts
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Worcester, MA 01655-0309
(508)856-2818
Fax (508)856-1680
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Cambridge, MA 02139
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(617)665-1671
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Occupational and Environmental Medicine
Boston Medical Center
88 E. Newton St., F-5
Boston, MA 02118
(617)353-6630
(617)353-6848
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Michigan

Michigan State University
Department of Medicine
117 West Fee

East Lansing, MI 48824-1316
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Fax (517)432-3606
Appts (517)353-4941
Kenneth Rosenman, MD

Division of Occupational and Environmental Medicine
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Department of Family Medicine
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Detroit, MI 48201
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Fax (313)493-5979
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Occupational Health Program
School of Public Health, University of Michigan
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Ann Arbor, MI 48109-2029
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Fax (734)763-8095
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Alt. Contact: Alfred Franzblau, MD

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Fax (248)559-8254
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1210 W. Saginaw
Lansing, MI 48915
(517)377-0309
Fax (517)377-0310
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Health Partners-Regions Hospital
Occupational and Environmental Medicine
640 Jackson St.
St. Paul, MN 55101-2595
(651)221-3771
Fax (651)221-8848
Paula Geiger
Alt. Contact: Michael McGrail, MD, MPH

Columbia Park Medical Group
Occupational Medicine Department
4000 Central Ave NE
Columbia Hts, MN 55421
(763)572-5710
Fax (763)571-3008
Donald Johnson, MD
Alt. Contact: Dorothy Quick

New Jersey

Environmental and Occupational Health Clinical Center
Environmental and Occupational Health Sciences Institute
UMDNJ - Robert Wood Johnson Medical School
170 Frelinghuysen Rd.
Piscataway, NJ 08854
(732)445-0123
Fax (732)445-0127
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Alt. Contact: Gail Buckler, RN, MPH, COHN-S

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Presbyterian Occupational Medicine Clinic
5901 Harper, NE
P.O. Box 26666
Albuquerque, NM 87125-6666
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Occupational and Environmental Medical Clinic
3751 Highway 528
Albuquerque, NM 87114
(505)272-2900
Fax (505)272-2909
Karen B. Mulloy, DO, MSCH

New York

Eastern NY Occupational and Environmental Health Center
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Albany, NY 12203
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Alt. Contact: Lynne Portnoy, MD, MPH

Mount Sinai - Irving J. Selikoff Center for Occupational and Environmental Medicine
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New York, NY 10029
(212)241-0176
Fax (212)996-0407
Appts (212)987-6043
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Center for Occupational and Environmental Medicine
School of Medicine
Health Sciences Center, Level 3-086
University at Stony Brook
Stony Brook, NY 11794
(516)444-2196
Fax (516)444-7525
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Central NY Occupational Health Clinical Center
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Occupational and Environmental Medicine Clinic
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New York, NY 10016
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Fax (212)562-4574
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Finger Lakes Occupational Health Services
980 Westfall Rd., Suite 210
Rochester, NY 14618
(716)256-0853
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Division of Occupational and Environmental Medicine
Duke University Medical Center
Box 3834
Durham, NC 27710
(919)286-3232
Fax (919)286-1021
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Alt. Contact: Gary Greenberg, MD, MPH

Ohio

Community Health Partners Occupational Health Center
The Lorain Clinic for
Occupational Medicine and Rehabilitation
1800 Livingston Ave.
Lorain, OH 44052
(440)233-1068
Fax (440)246-4560
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Center for Occupational Health
Holmes Hospital-Tate Wing
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Fax (513)584-1010
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University Occupational Health Services
Division of Occupational and Environmental Medicine
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Oklahoma City, OK 73104
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Oregon

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Oregon Health Sciences University (OHSU)
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Pennsylvania

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Texas Institute of Occupational Safety and Health
11937 U.S. Highway 271
Tyler, TX 75708-3154
(903)331-9447
Fax (903)531-9452
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University of Texas Health Services
7000 Fannin, Suite 1620
Houston, TX 77030
(713)500-3267
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Utah

Rocky Mountain Center for Occupational and Environmental Health
75 South 2000 East
University of Utah
Salt Lake City, UT 84112-0512
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Fax (801)581-3759
Appts (801)581-5056
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Washington

Occupational and Environmental Medicine Program
University of Washington Harborview Medical Center
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Seattle, WA 98104-2499
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Department of Family and Community Medicine
Marshall University School of Medicine
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Huntington, WV 25755
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Institute of Occupational and Environmental Health
West Virginia University School of Medicine
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University of Alberta
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Edmonton, Alberta, CD T6G 2G8
Harold Hoffman, MD
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MFL Occupational Health Centre, Inc.
102-275 Broadway
Winnipeg, Manitoba, CD R3C 4M6
(204)949-0811
Fax (204)956-0848
Carol Loveridge

Ontario

Occupational Health Clinics for Ontario Workers
15 Gervais Drive, Suite 308
Don Mills, ON Canada M3C 1Y8
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Fax (416)449-7772
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848 Main Street East
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Fax (905)549-7993
Chuck Emberson, Executive Director

Occupational Health Clinics for Ontario Workers
1780 Regent Street South
Times Square Mall
Sudbury, ON, Canada P3C 3Z8
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Windsor, ON, Canada N9A 4N1
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Fax (519)973-1906
Mary Parent, Executive Director

Occupational Health Clinics for Ontario Workers
171 Kendall St.
Point Edward, ON, Canada N7V 4G6
(519)337-4627
Margo Gilroy, Executive Director

COMMUNITY ORGANIZATIONS

Committees for Occupational Safety and Health (COSH) and similar organizations are comprised of rank-and-file workers, labor leaders, occupational safety and health professionals, medical professionals and community activists. They are an excellent source of current information. Many of them maintain libraries, and have professionals on staff who can provide technical assistance.

Alaska

Alaska Health Project
218 E. 4th Ave.
Anchorage, AK 99501
(907) 276-2864
Fax (907) 279-3089

California

LACOSH (Los Angeles)
5855 Venice Blvd.
Los Angeles, CA 90019
(323) 931-9000
Fax (323) 931-2255

SACOSH (Sacramento)
c/o Fire fighters, Local 522
3101 Stockton Blvd.
Sacramento, CA 95820
(916) 442-4390
Fax (916) 446-3057
email: akatten@mother.com

SCCOSH (Santa Clara)
760 N. First St., Second Floor
San Jose, CA 95112
(408) 998-4050
Fax (408) 998-4051
email: sccosh@igc.org

Worksafe/Francis Schreiberg
c/o San Francisco Labor Council
1188 Franklin St., Suite 203
San Francisco, CA 94109
(415) 433-5077 (Messages only)
Fax (415) 835-4913
email: fcs@kmes.com

Connecticut

ConnectiCOSH
77 Huyshope Ave., 2nd Floor
Hartford, CT 06106
(860) 549-1877
Fax (860) 251-6049
email: connecticosh@snet.net

Illinois

CACOSH
c/o Mike Ross
UIC School of Public Health
Great Lakes Center
M/C-922
2121 W. Taylor St.
Chicago, IL 60612-7260
(312)996-2747
Fax (312)413-7369
email: ross-mc@uic.edu

Maine

Maine Labor Group on Health
Box V
Augusta, ME 04330
(207)622-7823
Fax (207)622-3483 - or - 623-4916
email: migh@mint.net

Maryland

Alice Hamilton Occupational Health Center
1310 Apple Ave.
Silver Spring, MD 20910-3354
(301)565-4590
Fax (301)565-4596/97
email: bc74@telnet.umd.edu

Massachusetts

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555 Amory St.
Boston, MA 02130
(617)524-6686
Fax (617)524-3508
email: masscosh@shore.net

Western MassCOSH
458 Bridge St.
Springfield, MA 01103
(413)731-0760
Fax (413)731-6688
email: wmcosh@javanet.com

Michigan

SEMCOSH
1550 Howard St.
Detroit, MI 48216
(313)961-3345
Fax (313)961-3588
email: semcosh@mich.com

New Hampshire

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110 Sheep Davis Rd.
Pembroke, NH 03275
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Fax (603)225-1956
email: nhcosh@totalnetnh.net

North Carolina

NCOSH
P.O. Box 2514
Durham, NC 27715
(919)286-9249
Fax (919)286-4857
email: ncosh@igc.apc.org

Oregon

c/o Dick Edgington
ICWU-Portland
7440 SW 87 St.
Portland, OR 07223
(503)244-8429

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3001 Walnut St., 5th Floor
Philadelphia, PA 19104
(215)386-7000
Fax (215)386-3529
email: philaposh@aol.com

Rhode Island

RICOSH
741 Westminster St.
Providence, RI 02903
(401)751-2015
Fax (401)751-7520
email: jobhealth@juno.com

Wisconsin

WisCOSH
734 North 26th St.
Milwaukee, WI 53230
(414)933-2338
Fax (414)342-1998
email: wishcoshm@execpc.com

Canada

WOSH (Windsor)
547 Victoria Ave.
Windsor, Ontario N9A 4N1
(519)973-4800
Fax (519)973-1906
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Other Community Groups

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Asian Immigrant Women Advocates
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Oakland, CA 94607
(510)268-0192
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email: aiwa@igc.org

Labor Occupational Health Program (Bay Area)
2223 Fulton St., 4th Floor
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Fax (510)643-5698
email: lstock@uclink4.berkeley.edu

UCLA-LOSH Program
School of Public Policy & Social Research
Institute of Industrial Relations
6350 B Public Policy Bldg.
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DISTRICT OF COLUMBIA

Workers Institute for Occupational Safety and Health
1126 16th St., NW, Room 403
Washington, DC 20036
(202)887-1980
Fax (202)887-0191

LOUISIANA

Labor Studies Program / LA Watch
Institute of Human Relations
Loyola University
Box 12
New Orleans, LA 70118

(504)861-5830
Fax (504)861-5833

MASSACHUSETTS
Massachusetts Coalition on New Office Technology (CNOT)
650 Beacon St., 5th Floor
Boston, MA 02215
(617)247-6827
Fax (617)262-6414

MICHIGAN
Michigan Right-to-Act Campaign
Ecology Center of Ann Arbor
417 Detroit St.
Ann Arbor, MI 48104
(734)663-2400
Fax (734)663-2414
email: local223@aol.com

NEW JERSEY
New Jersey Work Environment Council
452 E. Third St.
Moorestown, NJ 08057
(609)866-9405
Fax (609)866-9708
email: RickEngler@aol.com

NEW YORK
Midstate Central Labor Coalition
123 S. Cayuga St., #204
Ithaca, NY 14850
(607)277-5670
Fax (607)277-8344
email: chf6@cornell.edu

OHIO
Greater Cincinnati Occupational Health Center
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Lower Level
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Fax (304)293-7163

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UNITED KINGDOM
London Hazards Centre
Interchange Studios
Dalby Street
London NW5 3NQ
(0171) 267-3387
Fax (0171) 267-3397
email: LONHAZ@MCR1.poptel.org.uk

Workers Health International Newsletter and HAZARDS Magazine
P.O. Box 199
Sheffield, S1 4YL
England
(+44 114) 276-5695
Fax (+44 114 276) 7257

INDUSTRY ORGANIZATIONS

Industry and trade associations allow their members to share information and work to promote the interests of the industry as a whole. Many of these associations actively participate in the development of regulations, and some sponsor research into the health and safety issues in their industry. These associations can also be a source of information regarding current practices in the industry. A few of the organizations that are active in health and safety issues are listed below. Most public libraries carry directories of these organizations, such as the annual *National Trade and Professional Associations of the U.S.*, which cross indexes organizations by subject.

American Hospital Association
One North Franklin
Chicago, Illinois 60606
(312)422-3000
Fax (312)422-4796
www.aha.org

American Iron and Steel Institute
1101 17th St. NW, Suite 1300
Washington, DC 20036
(202)452-7100
www.steel.org

American Petroleum Institute
1220 L St. NW
Washington, DC 20005-8029
(202)682-8000
www.api.org

American Welding Society
550 NW LeJeune Road
Miami, FL 33126
(800) 443-9353, Intl. (305) 443-9353
Fax (305)443-7559
www.aws.org

American Chemical Council
1300 Wilson Blvd.
Arlington, VA 22209
(703)741-5000
www.cmahq.com

Compressed Gas Association
1725 Jefferson Davis Hwy, Suite 1004
Arlington, VA 22202-4102
(703)979-0900
Fax (703)412-0128
www.cganet.com

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304 USA
(800)313-3774, (650)855-2000
www.epri.com

Safety Equipment Association (ISEA)
1901 N. Moore St. Ste 808
Arlington, VA 22209
(703)525-1695
Fax (703)528-2148
www.safetycentral.org/isea/

Semiconductor Industry Association
181 Metro Drive, Suite 450
San Jose, CA 95110
(408)436-6600
Fax (408)436-6646
www.semichips.org

Society of Plastics Engineers, Inc.
PO Box 403
Brookfield, CT 06804-0403
USA
(203)775-0471
Fax (203)775-8490
www.4spe.org

Labor Unions

Many labor unions maintain health and safety departments and are active in promoting and developing health and safety regulations. All of the labor organizations listed below have websites with health and safety pages. The health and safety departments of these unions can often provide information about the hazards in specific industries. The AFL-CIO website provides a page of links to affiliated unions.

American Federation of Labor - Congress of Industrial Organizations (AFL-CIO)
815 16th St., NW
Washington, DC 20006
(202)637-5000
Fax (202)637-5058
www.aflcio.org

American Federation of State, County and Municipal Employees (AFSCME)
1625 L Street, NW
Washington, DC 20036-5687
(202)429-1000
Fax (202)429-1293 TTY (202)659-0446
www.afscme.org

International Association of Machinists and Aerospace Workers (IAM)
9000 Machinists Place
Upper Marlboro, MD 20722-2687
(301)967-4500
www.iamaw.org

International Brotherhood of Teamsters
25 Louisiana Ave., NW
Washington, DC 20001
(202)624-6800
www.teamster.org

Union of Needle trades, Industrial and Textile Employees (UNITE)
1710 Broadway
New York, NY 10019
(212)265-7000
www.uniteunion.org

International Longshoremen's and Warehousemen's Union (ILWU)
1188 Franklin St.
San Francisco, CA 94109
(415)775-0533
Fax (415)775-1302
www.ilwu.org

Laborers' International Union of North America
905 16th St., NW
Washington, DC 20006
(202)737-8320
Fax (202)737-2754
www.liuna.org

Paper, Allied-Industrial, Chemical and Energy Workers International Union (PACE)
P.O. Box 1475
Nashville TN 37202
(615)834-8590
Fax (615)834-7741
www.paceunion.org

Service Employees' International Union (SEIU)
1313 L Street, NW
Washington, DC 20005
(202)898-3200
www.seiu.org

United Auto Workers (UAW)
8000 E. Jefferson Ave.
Detroit, MI 48214
(313)926-5000
www.uaw.org

United Farmworkers of America (UFW)
P.O. Box 62
Keene, CA 93531
(661)823-6252
Fax (661)823-6177
www.ufw.org

United Food and Commercial Workers International Union (UFCW)
1775 K Street, NW
Washington, DC 20006
(202)223-3111
www.ufcw.org

United Mine Workers of America (UMWA)
8315 Lee Hwy.
Fairfax VA 22031
(703)208-7200
www.umwa.org

United Steel Workers of America
Five Gateway Center
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REFERENCE MATERIALS

Internet Resources

In the five years since the last edition of this book there has been an explosion in the way the world accesses information: the Internet. In this short time the Internet has grown to be a worldwide phenomenon of communication.

There is a wide variety of search engines available free of charge to everyone. Here are some of our favorites.

www.rice.edu/Internet

This website is based at Rice University and gives instant access to many search engines. "Find resources by keyword" allows you to chose from among the leading search engines, as well as access the meta-search engines that will search multiple www indexes at once.

www.infoseek.go.com

Infoseek allows the searcher to narrow his or her search by choosing the "search within results" button, thereby focusing more succinctly on each pass.

www.altavista.com

Altavista "advanced search" uses boolean query, which is explained in the "advanced search cheat sheet."

www.berkeley.edu

For excellent Internet search ideas, go first to "Libraries", then "Under Web Searching - Search the Internet". This site suggests specialized databases for your subject area, suggestions for planning your Web search strategy, and detailed features of search engines.

A word of caution: Anyone can say anything on the Internet. It is an unedited morass of jewels and garbage. To be able to trust your Internet sources it is best to stick to web sites that are administered by a credible entity. Web addresses ending in *.gov* are government entities, and are usually excellent sources of accurate information. Likewise the suffix *.edu*, which indicates educational facilities, usually Universities. If you're in a University's online library catalog and you find something useful, it is most likely to be reliable, however, be aware that there are many web sites based at Universities that are just for fun. Remember to use common sense and proceed with caution.

Following are some of our favorite websites:

Centers for Disease Control and Prevention, home page
http://www.cdc.gov/ Provides on-line access to *Morbidity and Mortality Weekly Reports* and *Emerging Infectious Diseases*. You can also get an online subscription to these journals at this website.

Search the NIOSH website by keywords
http://www.cdc.gov/niosh/nioshsrch.html

OSU lab manual, include chemical hygiene plan, on-line search and download Word version.
http://www.pp.okstate.edu/ehs/HAZMAT/Labman.htm

EPA IRIS Substance list
http://www.epa.gov/ngispgm3/iris/subst-fl.htm

National Toxicology Program home page
http://ntp-server.niehs.nih.gov/

ATSDR Home Page
http://atsdr1.atsdr.cdc.gov:8080/atsdrhome.html
Search for chemical structure, and limited H&S info by chemical name, CAS number, or chemical structure.
http://www.chemexper.be/

NTP — Health and Safety Page — search form
http://ntp-server.niehs.nih.gov/Main_Pages/Chem-HS.html

California Department of Pesticide Regulation ingredients search: http://www.cdpr.ca.gov/docs/epa/epachem.htm

Canadian Centre for Occupational Safety and Health home page: http://www.ccohs.ca/

NIOSH Manual of Analytical Methods
http://www.cdc.gov/niosh/nmam/nmammenu.html

Department of Energy Home Page
http://www.doe.gov

Material Safety Data Sheets (Cornell) DOD database
http://msds.pdc.cornell.edu/

OSHA — establishment search
http://www.osha.gov/cgi-bin/est/est1

OSHA home page: http://www.osha.gov

OSHA Technical Links Home Page — includes the technical manual and much more
http://www.osha-slc.gov/SLTC/index.html

Chemfinder Searching From Camsoft.com
http://chemfinder.camsoft.com/

Index to OSHA Anaytical Methods
http://www.osha-slc.gov/SLTC/analytical_methods/index.html

Industrial Hygiene Resource Pages, by Deanna M. Ennis, CIH, CSP. Contains many good links and search advice.
http://freeweb.pdq.net/ennis/ih/index.htm

Howard Hughes Medical Institute Lab Safety Course
http://www.practicingsafescience.org/

TWI Job Knowledge for Welders — great information about welding processes
http://www.twi.co.uk/bestprac/jobknol/jobknol.html

EPA home page: http://www.epa.gov

Med Line (Pub Med), the NIH data base of medical and related journals. Search by keywords, download abstracts.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed

American Biological Safety Association
http://www.absa.org/index.html

OSHA Standards Interpretations
http://www.osha-slc.gov/OshDoc/toc_interps.html

American Chemical Society Home Page
http://www.acs.org/

International Health Care Worker Safety Center, contains information on safety devices and from the EPINET database.
http://www.med.virginia.edu/medcntr/centers/epinet/

Training for Development of Innovative Control Technologies. Contains much information on engineering controls to prevent needlesticks and other sharps injuries to health care workers. Includes recommendations for device evaluation criteria: http://www.tdict.org/newmenu.html

Sharps Injury Control Program, a joint project of the California Department of Health Services and the University of California. Contains a searchable list of safer sharps devices for health care workers.
http://www.ohb.org/sharps.htm

OSHA Sampling and Analytical Methods, downloadable in HTML format.
http://www.osha-slc.gov/dts/sltc/methods/toc.html

Hardin Meta Directory of Internet Health Sources — provides many links on toxicology and occupational medicine.
http://www.lib.uiowa.edu/hardin/md/index.html

Global Information Network on Chemicals. You can search IARC and many other databases, and access web-pages put up by a variety of governmental entities and NGOs.
http://www.nihs.go.jp/GINC/

National Ag Safety Database (NASD)
www.cdc.gov/niosh/nasd/nasdhome.html

International Labour Organization (ILO)
www.ilo.org

Department of Transportation, Emergency Response Guidebook: http://hazmat.dot.gov.gydebook.htm.

JOURNALS, MAGAZINES, NEWSLETTERS AND REPORTS

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Baltimore, MD: Williams & Wilkins Co.

American Journal of Epidemiology
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New York: Alan R. Liss

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Oxford, New York, etc: Pergamon Press
Applied Occupational and Environmental Hygiene
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ASHRAE Journal
New York: American Society of Heating, Refrigerating and Air Conditioning Engineers

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Silver City, NM: Interhemispheric Resource Center

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Horsham, Pa: LRP Publications

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Research Triangle Park, NC: U.S. Department of Health, Education and Welfare, Public Health Service, National Institutes of Health, National Institute of Environmental Health Sciences

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Philadelphia, PA: London, Taylor & Francis

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Washington, DC: Bureau of Labor Statistics, U.S. Department of Labor. Available from the Superintendent of Documents, U.S. Government Printing Office

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Rockville, Md: U.S. Public Health Services, Department of Health and Human Services

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There is a wealth of printed material available on various issues in industrial hygiene. The following bibliography is not meant to be exhaustive, but to point readers in the direction of a few interesting sources. Other references can be found in the individual chapters in this book. The material is organized in the following order:

- AIDS and Bloodborne Pathogens
- Biological Hazards
- Biological Monitoring and Medical Surveillance
- Engineering Controls
- Ergonomics
- Exposure and Risk Assessment
- History and Critiques of Industrial Hygiene Practice
- History of Worker Health and Safety
- Indoor Air Quality
- International Aspects
- Laboratory Health and Safety
- Noise and Hearing Conservation
- Occupational Epidemiology
- Occupational Health Policy
- Occupational Medicine
- People of Color
- Radiation Hazards
- Reproductive Hazards
- Resource Materials
- Right-to-Know and Hazard Communications
- Sampling and Laboratory Methods
- Toxicology and Chemical Hazards
- Ventilation
- Video Display Terminals
- Women

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Appendix B

ACGIH Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®)

Appendix

B

ACGIH Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®)

This appendix gives the Threshold Limit Values (TLVs®) for Chemical Substances and Physical Agents and the Biological Exposure Indices (BEIs®) that were adopted in 2001 by the American Conference of Governmental Industrial Hygienists, Inc. (ACGIH®). It is from the American Conference of Governmental Industrial Hygienists, Inc. (ACGIH®), 2001 Threshold Limit Values (TLVs®) for chemical Substances and Physical Agents and Biological Exposure Indices (*BEIs®*), *Copyright © 2001. Reprinted with permission.*

2001
TLVs® and BEIs®

Based on the Documentations of the

Threshold Limit Values

for Chemical Substances

and Physical Agents

&

Biological Exposure Indices

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ACGIH® is an organization devoted to the administrative and technical aspects of occupational and environ-mental health. The association has contributed substantially to the development and improvement of worker health protection. The Conference is a professional society, not a government agency.

The *Documentation of the Threshold Limit Values and Biological Exposure Indices* is the source publication for the TLVs® and BEIs® issued by ACGIH. That publication gives the pertinent scientific information and data with reference to literature sources that were used to base each TLV or BEI. For better understanding of the TLVs and BEIs, it is essential that the *Documentation* be consulted when the TLVs or BEIs are being used. For further information, contact The Science Group, ACGIH. The most up-to-date list of substances and agents under study by the Committees is available at www.acgih.org

Comments, suggestions, and requests for interpretations or technical information should be directed to the The Science Group at the address below or to the following E-mail address: science@acgih.org. To place of an order, contact Customer Service at the address below or use the following E-mail address: customerservice@acgih.org.

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POLICY STATEMENT ON THE USES OF TLVs AND BEIs

The Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®) are developed as guidelines to assist in the control of health hazards. These recommendations or guidelines are intended for use in the practice of industrial hygiene, to be interpreted and applied only by a person trained in this discipline. They are not developed for use as legal standards, and ACGIH® does not advocate their use as such. However, it is recognized that in certain circumstances individuals or organizations may wish to make use of these recommendations or guidelines as a supplement to their occupational safety and health program. The ACGIH will not oppose their use in this manner, if the use of TLVs and BEIs in these instances will contribute to the overall improvement in worker protection. However, the user must recognize the constraints and limitations subject to their proper use and bear the responsibility for such use.

The Introductions to the TLV/BEI Booklet and the TLV/BEI Documentation provide the philosophical and practical bases for the uses and limitations of the TLVs and BEIs. To extend those uses of the TLVs and BEIs to include other applications, such as use without the judgment of an industrial hygienist, application to a different population, development of new exposure/ recovery time models, or new effect endpoints, stretches the reliability and even viability of the database for the TLV or BEI as evidenced by the individual documentations.

It is not appropriate for individuals or organizations to impose on the TLVs or the BEIs their concepts of what the TLVs or BEIs should be or how they should be applied or to transfer regulatory standards requirements to the TLVs or BEIs.

The Policy Statement on the Uses of TLVs/BEIs was approved by the Board of Directors of ACGIH on March 1, 1988.

Special Note to User

The values listed in this publication are intended for use in the practice of industrial hygiene as guidelines or recommendations to assist in the control of potential workplace health hazards and for no other use. These values are *not* fine lines between safe and dangerous concentrations and *should not* be used by anyone untrained in the discipline of industrial hygiene. **It is imperative that the user of this publication read the Introduction to each section and be familiar with the *Documentation* of the TLVs and BEIs before applying the recommendations contained herein.** ACGIH disclaims liability with respect to the use of the TLVs and BEIs.

CONTENTS

Biologically Derived Airborne Contaminants

NEW MATERIAL OR REVISIONS FOR 2001

Chemical Substances

- Proposed TLVs on the 2000 Notice of Intended Changes (NIC) are adopted for the following substanced:
  - Butylated hydroxytoluene [BHT]
  - Glyoxal
  - Molybdenum and compounds
  - Propylene oxide
  - Refractory ceramic fibers
- New TLVs are proposed for the following and placed on the NIC:
  - tert-Amyl methyl ether [TAME]
  - 1-Chloro-2-propanol
  - 2-Chloro-1-propanol
  - Propionaldehyde
- Revisions to adopted TLVs are proposed and placed on the NIC for the following substances:
  - Acetonitrile
  - Azinphos-methyl
  - 2-Butoxyethanol
  - Captan
  - Chlorpyrifos
  - Diazinon
  - Dichlorvos
  - Disulfoton
  - 1-Hexene
  - Methyl tert-butyl ether [MTBE]
  - Molybdenum, soluble compounds
  - Monocrotophos
  - Parathion
  - Propylene
  - Silicon carbide
  - Sulfuric acid
  - Xylidine
- Previously proposed TLVs are retained on the NIC for the following substances:
  - Beryllium and compounds
  - Caprolactam
  - Demeton
  - Demeton-S-methyl
  - Dicrotophos
  - Dioxathion
  - 1,3-Dioxolane
  - Ethion
  - Ethyl benzene
  - Hydrogen sulfide
  - Isopropanol
  - Isopropyl acetate
  - Mevinphos
  - Naled
  - n-Propanol
  - Sodium sesquicarbonate [Trona]
  - Terbufos
  - Toluene-2,4-diisocyanate/ Toluene-2,6-diisocyanate
  - Trichlorphon
  - Turpentine
- The following substances are retained on the NIC with revised TLV recommendation:
  - Arsine
  - n-butanol
  - Cyclohexane
  - Diesel exhaust
  - Diesel fuel
  - 2-Ethylhexanoic acid
  - Oil mist, mineral
  - Wood dust
- The definition for the *"Sensitizer" Notation*, contained in the Introduction, is expanded.
- Synonyms previously contained in the alphabetical adopted TLVs section now reside in a special table following the Notice of Intended Changes.

Biological Exposure Indices (BEIs)

- Dichloromethane (methylene chloride) is retained on the NIC with the determinant in blood withdrawn.
- Revision of the BEIs for n-hexane and trichloroethylene are proposed and placed on the NIC.
- Notice of Intent to Establish a BEI for methyl n-butyl ketone is proposed.

Physical Agents

- Proposed TLVs on the 2000 NIC are adopted for the following agents:
  Hand Activity Level
  Lasers
  Noise, Notes 4 and 5
  Radiofrequency and Microwave Radiation
  Ultraviolet Radiation
- New TLVs are proposed for Lifting and appear under the *Ergonomics* section as a Notice of Intent to Establish.
- Revision to Note 2 of the Noise TLV is placed on the NIC.

Biologically Derived Airborne Contaminants

This section, originally residing in the "Introduction to the Chemical Substances," is now a stand-alone section of this book. At present, data do not support establishing TLVs or guidelines for exposure to biologically derived airborne contaminants. However, as research into the health effects associated with occupational and related bioaerosol exposure continues, ACGIH may develop exposure guidelines in the future. For the present, ACGIH recommends assessing and controlling bioaerosol exposures according to the guidance set forth in the ACGIH publication, *Bioerosols: Assessment and Control*.

Under Study

The reader is encouraged to review the "Under Study" lists appearing at the end of each section of this publication. Each Committee solicits information, especially data, that may assist in their deliberations regarding the substances, agents, and issues listed therein. Comments and suggestions, accompanied by substantive supporting data, should be forwarded, preferably in electronic format, to the The Science Group, ACGIH.

INTRODUCTION TO THE CHEMICAL SUBSTANCES

Threshold Limit Values (TLVs©) refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness. Smoking of tobacco is harmful for several reasons. Smoking may act to enhance the biological effects of chemicals encountered in the workplace and may reduce the body's defense mechanisms against toxic substances.

Individuals may also be hypersusceptible or otherwise unusually responsive to some industrial chemicals because of genetic factors, age, personal habits (e.g., smoking, alcohol, or other drugs), medication, or previous exposures. Such workers may not be adequately protected from adverse health effects from certain chemicals at concentrations at or below the threshold limits. An occupational physician should evaluate the extent to which such workers require additional protection.

TLVs are based on available information from industrial experience; from experimental human and animal studies; and, when possible, from a combination of the three. The basis on which the values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, nuisance, or other forms of stress may form the basis for others. Health impairments considered include those that shorten life expectancy, compromise physiological function, impair the capability for resisting other toxic substances or disease processes, or adversely affect reproductive function or developmental processes.

The amount and nature of the information available for establishing a TLV varies from substance to substance; consequently, the precision of the estimated TLV is also subject to variation and the latest TLV *Documentation* should be consulted in order to assess the extent of the data available for a given substance.

These limits are intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential workplace health hazards and for no other use, e.g., in the evaluation or control of community air pollution nuisances; in estimating the toxic potential of continuous, uninter-rupted exposures or other extended work periods; as proof or disproof of existing disease or physical condition; or adoption or use by countries whose working conditions or cultures differ from those in the United States of America and where sub-stances and processes differ. These limits *are not* fine lines between safe and dangerous concentrations nor are they a relative index of toxicity. They *should not* be used by anyone untrained in the discipline of industrial hygiene.

The TLVs, as issued by ACGIH, are recommendations and should be used as guidelines for good practices. In spite of the fact that serious adverse health effects are not believed likely as a result of exposure to the threshold limit concentrations, the best practice is to maintain concentrations of all atmospheric contaminants as low as is practical.

ACGIH disclaims liability with respect to the use of TLVs.

Notice of Intended Changes. Each year, proposed actions of the Chemical Substances TLV Committee for the forthcoming year are issued in the form of a "Notice of Intended Changes." This Notice provides an opportunity for comment and *solicits suggestions of substances to be added to the list. The suggestions should be accompanied by substantiating evidence.* The "Notice of Intended Changes" is presented after the Adopted Values in this section. Values listed in parentheses in the "Adopted" list are to be used during the period in which a proposed change for that Value is listed in the Notice of Intended Changes.

Definitions. Three categories of Threshold Limit Values (TLVs) are specified herein, as follows:

a) *Threshold Limit Value–Time-Weighted Average (TLV–TWA)*— the time-weighted average concentration for a conventional 8-hour workday and a 40-hour workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect.

b) *Threshold Limit Value–Short-Term Exposure Limit (TLV– STEL)* — the concentration to which it is believed that workers can be exposed continuously for a short period of time without suffering from 1) irritation, 2) chronic or irreversible tissue damage, or 3) narcosis of sufficient degree

to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency, and provided that the daily TLV–TWA is not exceeded. It is not a separate independent exposure limit; rather, it supplements the time-weighted average (TWA) limit where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature. STELs are recommended only where toxic effects have been reported from high short-term exposures in either humans or animals.

A STEL is defined as a 15-minute TWA exposure which should not be exceeded at any time during a workday even if the 8-hour TWA is within the TLV–TWA. Exposures above the TLV–TWA up to the STEL should not be longer than 15 minutes and should not occur more than four times per day. There should be at least 60 minutes between successive exposures in this range. An averaging period other than 15 minutes may be recommended when this is warranted by observed biological effects.

c) *Threshold Limit Value–Ceiling (TLV–C)* — the concentration that should not be exceeded during any part of the working exposure.

In conventional industrial hygiene practice if instantaneous monitoring is not feasible, then the TLV–C can be assessed by sampling over a period that should not exceed 15 minutes, except for those substances that may cause immediate irritation when exposures are short.

For some substances, e.g., irritant gases, only one category, the TLV–Ceiling, may be relevant. For other substances, one or two categories may be relevant, depending upon their physiologic action. It is important to observe that if any one of these types of TLVs is exceeded, a potential hazard from that substance is presumed to exist.

The Chemical Substances TLV Committee holds to the opinion that TLVs based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing evidence that physical irritation may initiate, promote, or accelerate physical impairment through interaction with other chemical or biologic agents.

Time-Weighted Average (TWA) vs Ceiling (C) Limits. TWAs permit excursions above the TLV provided they are compensated by equivalent excursions below the TLV–TWA during the workday. In some instances, it may be permissible to calculate the average concentration for a work-week rather than for a workday. The relationship between the TLV and permissible excursion is a rule of thumb and in certain cases may not apply. The amount by which the TLVs may be exceeded for short periods without injury to health depends upon a number of factors such as the nature of the contaminant, whether very high concentrations — even for short periods — produce acute poisoning, whether the effects are cumulative, the frequency with which high concentrations occur, and the duration of such periods. All factors must be taken into consideration in arriving at a decision as to whether a hazardous condition exists.

Although the TWA concentration provides the most satisfactory, practical way of monitoring airborne agents for compliance with the TLVs, there are certain substances for which it is inappropriate. In the latter group are substances which are predominantly fast acting and whose TLV is more appropriately based on this particular response. Sub-stances with this type of response are best controlled by a ceiling limit that should not be exceeded. It is implicit in these definitions that the manner of sampling to determine non-compliance with the limits for each group must differ; a single, brief sample, that is applicable to a ceiling limit, is not appropriate to the TWA; here, a sufficient number of samples are needed to permit determination of a TWA concentration throughout a complete cycle of operations or throughout the workshift.

Whereas the ceiling limit places a definite boundary that concentrations should not be permitted to exceed, the TWA requires an explicit limit to the excursions that are permissible above the listed TLVs. It should be noted that the same factors are used by the Chemical Substances TLV Committee in determining the magnitude of the value of the STEL or whether to include or exclude a substance for a ceiling listing.

Excursion Limits. For the vast majority of substances with a TLV–TWA, there is not enough toxicological data available to warrant a STEL. Nevertheless, excursions above the TLV–TWA should be controlled even where the 8-hour TLV–TWA is within recommended limits. Earlier editions of the TLV list included such limits whose values depended on the TLV–TWAs of the substance in question.

While no rigorous rationale was provided for these particular values, the basic concept was intuitive: in a well-controlled process exposure, excursions should be held within some reasonable limits. Unfortunately, neither toxicology nor collective industrial hygiene experience provide a solid basis for quantifying what those limits should be. The approach here is that the maximum recommended excursion should be related to variability generally observed in actual industrial processes. In reviewing large numbers of industrial hygiene surveys conducted by the National Institute for Occupational Safety and Health,

Leidel, Busch, and Crouse[1] found that short-term exposure measurements were generally log-normally distributed with geometric standard deviations mostly in the range of 1.5 to 2.0.

While a complete discussion of the theory and properties of the lognormal distribution is beyond the scope of this section, a brief description of some important terms is presented. The measure of central tendency in a lognormal description is the antilog of the mean logarithm of the sample values. The distribution is skewed, and the geometric mean is always smaller than the arithmetic mean by an amount which depends on the geometric standard deviation. In the lognormal distribution, the geometric standard deviation (sd_g) is the antilog of the standard deviation of the sample value logarithms and 68.26% of all values lie between m_g/sd_g and $m_g \times sd_g$.

If the short-term exposure values in a given situation have a geometric standard deviation of 2.0, 5% of all values will exceed 3.13 times the geometric mean. If a process displays a variability greater than this, it is not under good control and efforts should be made to restore control. This concept is the basis for the following excursion limit recommendations which apply to those TLV–TWAs that do not have STELs:

> *Excursions in worker exposure levels may exceed 3 times the TLV–TWA for no more than a total of 30 minutes during a workday, and under no circumstances should they exceed 5 times the TLV–TWA, provided that the TLV–TWA is not exceeded.*

The approach is a considerable simplification of the idea of the lognormal concentration distribution but is considered more convenient to use by the practicing industrial hygienist. If exposure excursions are maintained within the recommended limits, the geometric standard deviation of the concentration measurements will be near 2.0 and the goal of the recommendations will be accomplished.

When the toxicological data for a specific substance are available to establish a STEL, this value takes precedence over the excursion limit regard- less of whether it is more or less stringent.

"Skin" Notation. Listed substances followed by the designation "Skin" refer to the potential significant contribution to the overall exposure by the cutaneous route, including mucous membranes and the eyes, either by contact with vapors or, of probable greater significance, by direct skin contact with the substance. Vehicles present in solutions or mixtures can also significantly enhance potential skin absorption. It should be noted that while some materials are capable of causing irritation, dermatitis, and sensitization in workers, these properties are *not considered relevant* when assigning a skin notation. It should be noted, however, that the development of a dermatological condition can significantly affect the potential for dermal absorption.

While relatively limited quantitative data currently exist with regard to skin absorption of gases, vapors, and liquids by workers, the Chemical Substances TLV Committee recommends that the integration of data from acute dermal studies and repeated dose dermal studies in animals and/or humans, along with the ability of the chemical to be absorbed, be used in deciding on the appropriateness of the skin notation. In general, available data which suggest that the potential for absorption via the hands/forearms during the workday could be significant, especially for chemicals with lower TLVs, could justify a skin notation. From acute animal toxicity data, materials having a relatively low dermal LD_{50} (1000 mg/kg of body weight or less) would be given a skin notation. Where repeated dermal application studies have shown significant systemic effects following treatment, a skin notation would be considered. When chemicals penetrate the skin easily (higher octanol–water partition coefficients) and where extrapolations of systemic effects from other routes of exposure suggest dermal absorption may be important in the expressed toxicity, a skin notation would be considered.

Substances having a skin notation and a low TLV may present special problems for operations involving high airborne concentrations of the material, particularly under conditions where significant areas of the skin are exposed for a long period of time. Under these conditions, special precautions to significantly reduce or preclude skin contact may be required.

Biological monitoring should be considered to determine the relative contribution of exposure via the dermal route to the total dose. The TLV/BEI Booklet contains a number of adopted Biological Exposure Indices, which provide an additional tool when assessing the worker's total exposure to selected materials. For additional information, refer to "Dermal Absorption" in the "Introduction to the Biological Exposure Indices," 6th edition of the *Documentation of Threshold Limit Values and Biological Exposure Indices*, and to Leung and Paustenbach.[2]

Use of the skin designation is intended to alert the reader that air sampling alone is insufficient to accurately quantitate exposure and that measures to prevent significant cutaneous absorption may be required.

"Sensitizer" Notation. The designation "SEN" in the "Notations" column refers to the potential for an agent to produce sensitization, as confirmed by animal or human data. The SEN notation does not imply that sensitization is the critical effect on which the TLV is based, nor does it imply that this effect is the sole basis for that agent's TLV. If sensitization data exist, they are carefully considered when recommending the TLV for the agent. For those TLVs that are based upon sensitization, they are meant to protect workers from induction of this effect and are not intended to protect those workers who have already become sensitized.

In the workplace, respiratory, dermal, or conjunctival exposures to sensitizing agents may occur. Similarly, sensitizers may evoke respiratory, dermal, or conjunctival reactions. At this time, the notation does not distinguish between sensitization involving any of these organ systems. The absence of a SEN notation does not signify that the agent lacks the ability to produce sensitization but may reflect the paucity or inconclusiveness of scientific evidence.

Sensitization often occurs via an immunological mechanism and is not to be confused with other conditions or terminology such as hyperreactivity, susceptibility, or sensitivity. Initially, there may be little or no response to a sensitizing agent. However, after a person is sensitized, subsequent exposure may cause intense responses, even at low exposure concentrations (well below the TLV). These reactions may be life-threatening and may have an immediate or delayed onset. Workers who have become sensitized to a particular agent may also exhibit cross-reactivity to other agents with similar chemical structures. A reduction in exposure to the sensitizer and its structural analogs generally reduces the incidence of allergic reactions among sensitized individuals. For some sensitized individuals, however, complete avoidance in occupational and nonoccupational settings provides the only means to prevent the immune responses to recognized sensitizing agents and their structural analogs.

Agents having a SEN notation and a low TLV present special problems in the workplace. Respiratory, dermal, and conjunctival exposures should be significantly reduced or eliminated using personal protective equipment and process control measures. Education and training (e.g., review of potential health effects, safe handling procedures, emergency information) are also necessary for those who work with known sensitizing agents.

For additional information regarding the sensitization potential of a particular agent, refer to the Documentation for the specific agent.

Mixtures. Special consideration should be given also to the application of the TLVs in assessing the health hazards that may be associated with exposure to mixtures of two or more substances. A brief discussion of basic considerations involved in developing TLVs for mixtures and methods for their development, amplified by specific examples, are given in Appendix C.

Particulate Matter. For solid and liquid particulate matter, TLVs are expressed in terms of total particulate, except where the terms inhalable, thoracic, or respirable particulate are used. Refer to Endnotes. See Appendix D, Particle Size-Selective Sampling Criteria for Airborne Particulate Matter, for the definitions of inhalable, thoracic, and respirable particulate matter. The term total particulate refers to air-borne material sampled with the 37-mm closed-face cassette traditionally used in the United States for aerosol sampling.

The intent of the Chemical Substances TLV Committee is to replace all total particulate TLVs with inhalable, thoracic, or respirable particulate matter TLVs. All proposed changes will be included on the Notice of Intended Changes and comments invited. Publication of the results of side-by-side sampling studies using older total and newer inhalable, thoracic, or respirable sampling techniques is encouraged to aid in the appropriate replacement of current total particulate TLVs.

Particulates (Insoluble) Not Otherwise Specified (PNOS). There are many substances with TLVs and many more without TLVs for which there is no evidence of specific toxic effects. Those that are particulates have frequently been called "nuisance dusts." Although these materials may not cause fibrosis or systemic effects, they are not biologically inert. At high concentrations, otherwise nontoxic particulates have been associated with the occasionally fatal condition known as alveolar proteinosis. At lower concentrations, they can inhibit the clearance of toxic particulates from the lung by decreasing the mobility of the alveolar macrophages. Accordingly, the Chemical Substances TLV Committee recommends the use of the term "Particulates Not Otherwise Specified (PNOS)" to emphasize that all materials are potentially toxic and to avoid the implication that these materials are harmless at all exposure concentrations. Particulates identified under the PNOC heading are those containing no asbestos and < 1% crystalline silica. To recognize the adverse effects of exposure to otherwise nontoxic particulate matter, a TLV–TWA of 10 mg/m^3 for inhalable particulate and a TLV–TWA of 3 mg/m^3 for respirable particulate have been

established and are included in the adopted TLV section. Refer to the Documentation for Particulates (Insoluble) Not Otherwise Specified (PNOS) for a complete discussion of this subject.

Simple Asphyxiants—"Inert" Gases or Vapors. A number of gases and vapors, when present in high concentrations in air, act primarily as simple asphyxiants without other significant physiologic effects. A TLV may not be recommended for each simple asphyxiant because the limiting factor is the available oxygen. The minimal oxygen content should be 18% by volume under normal atmospheric pressure (equivalent to a partial pressure, pO_2 of 135 torr). Atmospheres deficient in O_2 do not provide adequate warning and most simple asphyxiants are odorless. Several simple asphyxiants present an explosion hazard. Account should be taken of this factor in limiting the concentration of the asphyxiant.

Biological Exposure Indices (BEI). The note "BEI" is listed in the "Notations" column when a BEI is also recommended for the substance listed. Biological monitoring should be instituted for such substances to evaluate the total exposure from all sources, including dermal, ingestion, or non-occupational. See the BEI section and the *Documentation of the TLVs and BEIs* for the substance.

Physical Factors. It is recognized that such physical factors as heat, ultraviolet and ionizing radiation, humidity, abnormal pressure (altitude), and the like may place added stress on the body so that the effects from exposure at a TLV may be altered. Most of these stresses act adversely to increase the toxic response of a substance. *Although most TLVs have built-in safety factors to guard against adverse effects to moderate deviations* from normal environments, the safety factors of most substances are not of such a magnitude as to take care of gross deviations. For example, continuous, heavy work at temperatures above 25°C WBGT, or overtime extending the workweek more than 25%, might be considered gross deviations. In such instances, judgment just be exercised in the proper adjustments of the TLVs.

Unlisted Substances. The list of TLVs is by no means a complete list of all hazardous substances or of all hazardous substances used in industry. For a large number of materials of recognized toxicity, little or no data are available that could be used to establish a TLV. Substances that do not appear on the TLV list should not be considered to be harmless or nontoxic. When unlisted sub-stances are introduced into a workplace, the medical and scientific literature should be reviewed to identify potentially dangerous toxic effects. It may also be advisable to conduct preliminary toxicity studies. In any case, it is necessary to remain alert to adverse health effects in workers which may be associated with the use of new materials. The TLV Committee strongly encourages industrial hygienists and other occupational health professionals to bring to the Commit-tee's attention any information which would suggest that a TLV should be established. Such information should include exposure concentrations and correlated health effects data (dose–response) that would support a recommended TLV.

Unusual Work Schedules. Application of TLVs to workers on work schedules markedly different from the conventional 8-hour day, 40-hour week requires particular judgment in order to provide, for such workers, protection equal to that provided to workers on conventional workshifts.

As tentative guidance, field hygienists are referred to the "Brief and Scala model" which is described and explained at length in Patty.[3]

The Brief and Scala model reduces the TLV proportionately for both increased exposure time and reduced recovery (nonexposure) time. The model is generally intended to apply to work schedules longer than 8 hours/day or 40 hours/week. The model should not be used to justify very high exposures as "allowable" where the exposure periods are short (e.g., exposure to 8 times the TLV–TWA for one hour and zero exposure during the remainder of the shift). In this respect, the general limitations on TLV excursions and STELs should be applied to avoid inappropriate use of the model with very short exposure periods or shifts.

Since adjusted TLVs do not have the benefit of historical use and long-time observation, medical supervision during initial use of adjusted TLVs is advised. In addition, the hygienist should avoid unnecessary exposure of workers even if a model shows such exposures to be "allowable" and should not use models to justify higher-than-necessary exposures.

The Brief and Scala model is easier to use than some of the more complex models based on pharmacokinetic actions. However, hygienists thoroughly familiar with such models may find them more appropriate in specific instances. Use of such models usually requires knowledge of the biological half-life of each substance, and some models require additional data.

Short workweeks can allow workers to have two full-time jobs, perhaps with similar exposures, and may result in overexposure even if neither job by itself entails overexposure. Hygienists should be alert to such situations.

Conversion of TLVs in ppm to mg/m³. TLVs for gases and vapors are usually established in

terms of parts per million of sub-stances in air by volume (ppm). For convenience to the user, these TLVs are also listed with molecular weights. Where 24.45 = molar volume of air in liters at normal temperature and pressure (NTP) conditions (25°C and 760 torr), the conversion equation for mg/m^3 is:

$$\text{TLV in mg/m}^3 = \frac{(\text{TLV in ppm})(\text{gram molecular weight of substance})}{24.45}$$

Conversely, the equation for converting TLVs in mg/m^3 to ppm is:

$$\text{TLV in ppm} = \frac{(\text{TLV in mg/m}^3)(24.45)}{\text{gram molecular weight of substance}}$$

The above equation may be used to convert TLVs to any degree of precision desired. When converting TLVs to mg/m^3 for other temperatures and pressures, the reference TLVs should be used as a starting point. When converting values expressed as an element (e.g., as Fe, as Ni), the molecular value of the element should be used, not that of the entire compound.

In making conversions for substances with variable molecular weights, appropriate molecular weights should be estimated or assumed (see the TLV Documentation).

References

1. Leidel, N.A.; Busch, K.A.; Crouse, W.E.: Exposure Measurement Action Level and Occupational Environmental Variability. DHEW (NIOSH) Pub. No. 76-131; NTIS Pub. No. PB- 267-509. National Technical Information Service, Springfield, VA (December 1975).
2. Leung, H.; Paustenbach, D.J.: Techniques for Estimating the Percutaneous Absorption of Chemicals Due to Occupational and Environmental Exposure. Appl. Occup. Environ. Hyg. 9(3):187–197 (March 1994).
3. Paustenbach, D.J.: Occupational Exposure Limits, Pharmacokinetics, and Unusual work Schedules. In: Patty's Industrial Hygiene and Toxicology, 3rd ed., Vol. 3A, The Work Environment, Chap. 7, pp. 222–348. R.L. Harris, L.J. Cralley, and L.V., Cralley, Eds. John Wiley and Sons, Inc., New York (1994).

COMMON SYNONYMS

Synonym	TLV Listing
Acetylene dichloride	1,2-Dichloroethylene
α-Alumina	Aluminum oxide
2-Aminoethanol	Ethanolamine
3-Amino-1,2,4-triazole	Amitrole
Amosite	Asbestos
n-Amyl acetate	Pentyl acetate (all isomers)
sec-Amyl acetate	Pentyl acetate (all isomers)
p-Benzoquinone	Quinone
Bromochloromethane	Chlorobromomethane
Butanethiol	Butyl mercaptan
2-Butanone	Methyl ethyl ketone (MEK)
Carbonyl chloride	Phosgene
2-Chloro-1,3-butadiene	beta-Chloroprene
1-Chloro-2,3-epoxy propane	Epichlorohydrin
2-Chloroethanol	Ethylene chlorohydrin
Chloroethylene	Vinyl chloride
2-Chloro-6-(trichloromethyl) pyridine	Nitrapyrin
Chrysotile,	Asbestos
Cristobalite	Silica—Crystalline
Crocidolite	Asbestos
1,2-Diaminoethane	Ethylenediamine
Diatomaceous earth	Silica — Amorphous
1,2-Dibromoethane	Ethylene dibromide
2,6-Di-tert-butyl-p-cresol	Butylated hydroxytoluene (BHT)
1,2-Dichloroethane	Ethylene dichloride
1,1-Dichloroethylene	Vinylidene chloride
1,2-Dichloropropane	Propylene dichloride
Diethyl ether	Ethyl ether
Dihydroxybenzene	Hydroquinone
Dimethoxymethane	Methylal
Dimethylaminobenzene	Xylidine
Dimethylbenzene	Xylene
Dimethyl-1,2-dibromo-2,2-dichloroethyl phosphate	Naled
2,6-Dimethyl-4-heptanone	Diisobutyl ketone
Dimethylnitrosoamine	N-Nitrosodimethylamine
3,5-Dinitro-o-toluamide	Dinitolmide
Diphenyl	Biphenyl
Diphenylmethane diisocyanate	Methylene bisphenyl isocyanate
Dipropoylene glycol methyl ether	bis-(2-Methoxypropyl) ether
Di-sec-octyl phthalate	Di(2-ethylhexyl)phthalate
Enzymes	Subtilisins
1,2-Epoxypropane	Propylene oxide
2,3-Epoxy-1-propanol	Glycidol
Ethanethiol	Ethyl mercaptan
Ethyl alcohol	Ethanol
Ethylene glycol methyl ether acetate	2-Methoxyethyl acetate
Ethylidene chloride	1,1-Dichloroethane
Fibrous glass dust	Synthetic Vitreous Fibers
Fluorotrichloromethane	Trichlorofluoromethane
Glass, fibrous or dust	Synthetic Vitreous Fibers
Glycol monoethyl ether	2-Ethoxyethanol
Gypsum	Calcium sulfate
2-Heptanone	Methyl n-amyl ketone
3-Heptanone	Ethyl butyl ketone
2-Hexanone	Methyl n-butyl ketone
4-Hydroxy-4-methyl-2-pentanone	Diacetone alcohol
Isoamyl acetate	Pentyl acetate (all isomers)
Isopropyl alcohol	Isopropanol
Limestone	Calcium carbonate
Marble	Calcium carbonate
Methanethiol	Methyl mercaptan
Methyl alcohol	Methanol
Methylene chloride	Dichloromethane
Methyl amyl alcohol	Methyl isobutyl carbinol
5-Methyl-3-heptanone	Ethyl amyl ketone
Mineral wool fiber	Synthetic Vitreous Fibers
Monochlorobenzene	Chlorobenzene
Nickel sulfide roasting, fume & dust	Nickel subsulfide
Nitrochloromethane	Chloropicrin
Nuisance particulates	Particulates (Insoluble) Not Otherwise Specified (PNOS)
Particulate polycyclic aromatic hydrocarbons (PPAH)	Coal tar pitch volatiles
2-Pentanone	Methyl propyl ketone
Perchloroethylene	Tetrachloroethylene
Petroleum distillates	Gasoline; Stoddard Solvent; VM&P naphtha
Phenacyl chloride	alpha-Chloroacetophenone
Phenylethylene	Styrene, monomer
Phosdrin	Mevinphos
2-Pivalyl-1,3-indandione	Pindone
Plaster of Paris	Calcium sulfate
Polychlorobiphenyls	Chlorodiphenyls
Precipitated silica	Silica — Amorphous
Propylene glycol monomethyl ether	1-Methoxy-2-propanol
Propyne	Methyl acetylene
Pyrocatechol	Catechol
Quartz	Silica — Crystalline
Silane	Silicon tetrahydride
Sodium 2,4-dichlorophenoxyethyl sulfate	Sesone
Stibine	Antimony hydride
Systox	Demeton
TEDP	Sulfotep
Tetrachloromethane	Carbon tetrachloride
Toluol	Toluene
Toxaphene	Chlorinated camphene
1,1,1-Trichloroethane	Methyl chloroform
Trichloromethane	Chloroform
Trichloronitromethane	Chloropicrin
Tricyclohexyltin hydroxide	Cyhexatin
Tridymite	Silica — Crystalline
2,4,6-Trinitrophenol	Picric acid
2,4,6-Trinitrophenylmethylnitramine	Tetryl
Tripoli	Silica — Crystalline
Vinyl benzene	Styrene
Vinyl cyanide	Acrylonitrile

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Acetaldehyde [75-07-0]	—	C 25 ppm	A3	44.05	Irritation
Acetic acid [64-19-7]	10 ppm	15 ppm	—	60.00	Irritation
Acetic anhydride [108-24-7]	5 ppm	—	—	102.09	Irritation
Acetone [67-64-1]	500 ppm	750 ppm	A4; BEI	58.05	Irritation
Acetone cyanohydrin [75-86-5] , as CN	—	C 4.7 ppm	Skin	85.10	CNS; anoxia
‡ Acetonitrile [75-05-8]	(40 ppm)	(60 ppm)	(—); A4	41.05	Lung; anoxia
Acetophenone [98-86-2]	10 ppm	—	—	120.15	Irritation; ocular
Acetylene [74-86-2]		Simple asphyxiant (D)		26.02	Asphyxiation
Acetylene tetrabromide [79-27-6]	1 ppm	—	—	345.70	Irritation; liver
Acetylsalicylic acid (Aspirin) [50-78-2]	5 mg/m^3	—	—	180.15	Blood
Acrolein [107-02-8]	—	C 0.1 ppm	Skin; A4	56.06	Irritation; pulmonary edema
Acrylamide [79-06-1]	0.03 mg/m^3	—	Skin; A3	71.08	CNS; dermatitis
Acrylic acid [79-10-7]	2 ppm	—	Skin; A4	72.06	Irritation; reproductive
Acrylonitrile [107-13-1]	2 ppm	—	Skin; A3	53.05	Cancer
Adipic acid [124-04-9]	5 mg/m^3	—	—	146.14	Neurotoxicity; GI; irritation
Adiponitrile [111-69-3]	2 ppm	—	Skin	108.10	Lung
Aldrin [309-00-2]	0.25 mg/m^3	—	Skin; A3	364.93	Liver
Allyl alcohol [107-18-6]	0.5 ppm	—	Skin; A4	58.08	Irritation
Allyl chloride [107-05-1]	1 ppm	2 ppm	A3	76.50	Liver
Allyl glycidyl ether (AGE) [106-92-3]	1 ppm	—	A4	114.14	Irritation; dermatitis; sensitization
Allyl propyl disulfide [2179-59-1]	2 ppm	3 ppm	—	148.16	Irritation
Aluminum [7429-90-5] and Compounds, as Al					
Metal dust	10 mg/m^3	—	—	26.98	Irritation
Pyro powders	5 mg/m^3	—	—		Lung
Welding fumes	5 mg/m^3	—	B2		Irritation
Soluble salts	2 mg/m^3	—	—		Irritation
Alkyls (NOS)		—	—		Irritation
Aluminum oxide [1344-28-1]	10 mg/m^3 (E)	—	A4	101.96	Lung; irritation
4-Aminodiphenyl [92-67-1]	—	—	Skin; A1	169.23	Cancer (bladder)
2-Aminopyridine [504-29-0]	0.5 ppm	—	—	91.11	CNS
Amitrole (3-Amino-1,2,4-triazole) [61-82-5]	0.2 mg/m^3	—	A3	84.08	Reproductive; thyroid
Ammonia [7664-41-7]	25 ppm	35 ppm	—	17.03	Irritation
Ammonium chloride fume [12125-02-9]	10 mg/m^3	20 mg/m^3	—	53.50	Irritation
Ammonium perfluorooctanoate [3825-26-1]	0.01 mg/m^3	—	Skin; A3	431.00	Liver
Ammonium sulfamate [7773-06-0]	10 mg/m^3	—	—	114.13	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Aniline [62-53-3]	2 ppm	—	Skin; A3; BEI	93.12	Anoxia
o-Anisidine [90-04-0]	0.1 ppm	—	Skin; A3	123.15	Anoxia
p-Anisidine [104-94-9]	0.1 ppm	—	Skin; A4	123.15	Anoxia
Antimony [7440-36-0] and compounds, as Sb	0.5 mg/m^3	—	—	121.75	Irritation; lung; CVS
Antimony hydride (Stibine) [7803-52-3]	0.1 ppm	–	–	124.78	Irritation; blood
Antimony trioxide [1309-64-4] production	—	—	A2	171.50	Cancer (lung); pneumoconiosis
ANTU [86-88-4]	0.3 mg/m^3	—	A4	202.27	Lung; irritation
Argon [7440-37-1]		Simple asphyxiant (D)		39.95	Asphyxiation
Arsenic [7440-38-2] and inorganic compounds, as As	0.01 mg/m^3	—	A1; BEI	74.92 Varies	Cancer (lung, skin); lung
‡ Arsine [7784-42-1]	(0.05) ppm	—	(—)	77.95	Blood; kidney
Asbestos, all forms	0.1 f/cc (F)	—	A1	NA	Asbestosis.; cancer
* Asphalt (Bitumen) fume [8052-42-4], as benzene-soluble aerosol	0.5 mg/m^3 (I)	—	A4	—	Irritation; lung; burns
Atrazine [1912-24-9]	5 mg/m^3	—	A4	216.06	Irritation
‡ Azinphos-methyl [86-50-0]	(0.2) mg/m^3	—	Skin; (—);A4; BEI	317.34	Cholinergic
Barium [7440-39-3] and soluble compounds, as Ba	0.5 mg/m^3	—	A4	137.30	Irritation; GI; muscles
Barium sulfate [7727-43-7]	10 mg/m^3	—	—	233.43	Pneumoconiosis (baritosis)
Benomyl [17804-35-2]	10 mg/m^3	—	A4	290.32	Dermatitis; irritation; reproductive
Benz[a]anthracene [56-55-3]	—(L)	—	A2	228.3	Cancer
Benzene [71-43-2]	0.5 ppm	2.5 ppm	Skin; A1; BEI	78.11	Cancer
Benzidine [92-87-5]	—(L)	—	Skin; A1	184.23	Cancer (bladder)
Benzo[b]fluoranthene [205-99-2]	—(L)	—	A2	252.30	Cancer
Benzo[a]pyrene [50-32-8]	—(L)	—	A2	252.30	Cancer
Benzotrichloride [98-07-7]	—	C 0.1 ppm	Skin; A2	195.50	Irritation; cancer
Benzoyl chloride [98-88-4]	—	C 0.5 ppm	A4	140.57	Irritation
Benzoyl peroxide [94-36-0]	5 mg/m^3	—	A4	242.22	Irritation
Benzyl acetate [140-11-4]	10 ppm	—	A4	150.18	Irritation
Benzyl chloride [100-44-7]	1 ppm	—	A3	126.58	Irritation; lung
‡ Beryllium [7440-41-7] and compounds, as Be	(0.002 mg/m^3)	(0.01 mg/m^3)	(—); A1	9.01	Cancer (lung); berylliosis
Biphenyl [92-52-4]	0.2 ppm	—	—	154.20	Lung
Bis(2-dimethylaminoethyl)ether (DMAEE) [3033-62-3]	0.05 ppm	0.15 ppm	Skin	160.26	Irritation; vision

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Bismuth telluride				800.83	
Undoped [1304-82-1]	10 mg/m^3	—	A4		Irritation
Se-doped, as Bi_2Te_3	5 mg/m^3	—	A4		Irritation; lung
Borates, tetra, sodium salts					Irritation
Anhydrous [1330-43-4]	1 mg/m^3	—	—	201.27	
Decahydrate [1303-96-4]	5 mg/m^3	—	—	301.37	
Pentahydrate [12179-04-3]	1 mg/m^3	—	—	291.30	
Boron oxide [1303-86-2]	10 mg/m^3	—	—	69.64	Irritation
Boron tribromide [10294-33-4]	—	C 1 ppm	—	250.57	Irritation; burns
Boron trifluoride [7637-07-2]	—	C 1 ppm	—	67.82	Irritation
Bromacil [314-40-9]	10 mg/m^3	—	A3	261.11	Irritation
Bromine [7726-95-6]	0.1 ppm	0.2 ppm	—	159.81	Irritation
Bromine pentafluoride [7789-30-2]	0.1 ppm	—	—	174.92	Irritation
Bromoform [75-25-2]	0.5 ppm	—	Skin; A3	252.80	Irritation; liver
1,3-Butadiene [106-99-0]	2 ppm	—	A2	54.09	Cancer
Butane [106-97-8]	800 ppm	—	—	58.12	Narcosis
‡ n-Butanol [71-36-3]	—	(C 50 ppm)	(Skin)	74.12	Irritation; ototoxic; ocular
sec-Butanol [78-92-2]	100 ppm	—	—	74.12	Irritation; narcosis
tert-Butanol [75-65-0]	100 ppm	—	A4	74.12	Narcosis; irritation
‡ 2-Butoxyethanol (EGBE) [111-76-2]	20 ppm	—	(Skin)	118.17	Irritation; CNS
n-Butyl acetate [123-86-4]	150 ppm	200 ppm	—	116.16	Irritation
sec-Butyl acetate [105-46-4]	200 ppm	—	—	116.16	Irritation
tert-Butyl acetate [540-88-5]	200 ppm	—	—	116.16	Irritation
n-Butyl acrylate [141-32-2]	2 ppm	—	SEN; A4	128.17	Irritation; reproductive
n-Butylamine [109-73-9]	—	C 5 ppm	Skin	73.14	Irritation
* Butylated hydroxytoluene (BHT) [128-37-0]	2 mg/m$^{3(I,V)}$	–	A4	220.34	Irritation
tert-Butyl chromate, as CrO_3 [1189-85-1]	—	C 0.1 mg/m^3	Skin	230.22	Irritation; lung
n-Butyl glycidyl ether (BGE) [2426-08-6]	25 ppm	—	—	130.21	Irritation; sensitization
n-Butyl lactate [138-22-7]	5 ppm	—	—	146.19	Irritation; headache
n-Butyl mercaptan [109-79-5]	0.5 ppm	—	—	90.19	Irritation; CNS; reproductive
o-sec-Butylphenol [89-72-5]	5 ppm	—	Skin	150.22	Irritation
p-tert-Butyl toluene [98-51-1]	1 ppm	—	—	148.18	Irritation; CNS; CVS
Cadmium [7440-43-9] and compounds, as Cd	0.01 mg/m^3	—	A2; BEI	112.40	Kidney
	0.002 mg/m^3 (R)	—	A2; BEI	Varies	
Calcium carbonate [1317-65-3]	10 mg/m^3 (E)	—	—	100.09	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Calcium chromate [13765-19-0], as Cr	0.001 mg/m^3	—	A2	156.09	Cancer
Calcium cyanamide [156-62-7]	0.5 mg/m^3	—	A4	80.11	Irritation; dermatitis
Calcium hydroxide [1305-62-0]	5 mg/m^3	—	—	74.10	Irritation
Calcium oxide [1305-78-8]	2 mg/m^3	—	—	56.08	Irritation
Calcium silicate (synthetic) [1344-95-2]	10 mg/m^3 (E)	—	A4	—	Irritation
Calcium sulfate [7778-18-9]	10 mg/m^3 (E)	—	—	136.14	Irritation
Camphor, synthetic [76-22-2]	2 ppm	4 ppm	A4	152.23	Irritation; anosmia
‡ Caprolactam [105-60-2] (Particulate) (Vapor)	 (1 mg/m^3) (5 ppm)	 (3 mg/m^3) (10 ppm)	 (A4) (A4)	113.16	Irritation
Captafol [2425-06-1]	0.1 mg/m^3	—	Skin; A4	349.06	Dermatitis; sensitization
‡ Captan [133-06-2]	(5 mg/m^3)	—	(—); A3	300.60	Irritation
Carbaryl [63-25-2]	5 mg/m^3	—	A4	201.20	Cholinergic; reproductive
Carbofuran [1563-66-2]	0.1 mg/m^3	—	A4	221.30	Cholinergic
Carbon black [1333-86-4]	3.5 mg/m^3	—	A4	—	Lung
Carbon dioxide [124-38-9]	5000 ppm	30,000 ppm	—	44.01	Asphyxiation
Carbon disulfide [75-15-0]	10 ppm	—	Skin; BEI	76.14	CVS; CNS
Carbon monoxide [630-08-0]	25 ppm	—	BEI	28.01	Anoxia; CVS; CNS; reproductive
Carbon tetrabromide [558-13-4]	0.1 ppm	0.3 ppm	—	331.65	Irritation; liver
Carbon tetrachloride (Tetrachloromethane) [56-23-5]	5 ppm	10 ppm	Skin; A2	153.84	Liver; cancer
Carbonyl fluoride [353-50-4]	2 ppm	5 ppm	—	66.01	Irritation; bone; fluorosis
Catechol [120-80-9]	5 ppm	—	Skin; A3	110.11	Irritation; CNS; lung
Cellulose [9004-34-6]	10 mg/m^3	—	—	NA	Irritation
Cesium hydroxide [21351-79-1]	2 mg/m^3	—	—	149.92	Irritation
Chlordane [57-74-9]	0.5 mg/m^3	—	Skin; A3	409.80	Seizures; liver
Chlorinated camphene (Toxaphene) [8001-35-2]	0.5 mg/m^3	1 mg/m^3	Skin; A3	414.00	Seizures; liver
o-Chlorinated diphenyl oxide [31242-93-0]	0.5 mg/m^3	—	—	377.00	Chloracne; liver
Chlorine [7782-50-5]	0.5 ppm	1 ppm	A4	70.91	Irritation
Chlorine dioxide [10049-04-4]	0.1 ppm	0.3 ppm	—	67.46	Irritation; bronchitis
Chlorine trifluoride [7790-91-2]	—	C 0.1 ppm	—	92.46	Irritation; lung
Chloroacetaldehyde [107-20-0]	—	C 1 ppm	—	78.50	Irritation
Chloroacetone [78-95-5]	—	C 1 ppm	Skin	92.53	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
2-Chloroacetophenone [532-27-4]	0.05 ppm	—	A4	154.59	Irritation; sensitization
Chloroacetyl chloride [79-04-9]	0.05 ppm	0.15 ppm	Skin	112.95	Irritation; lung
Chlorobenzene [108-90-7]	10 ppm	—	A3; BEI	112.56	Liver
o-Chlorobenzylidene malononitrile [2698-41-1]	—	C 0.05 ppm	Skin; A4	188.61	Irritation
Chlorobromomethane [74-97-5]	200 ppm	—	—	129.39	CNS; liver
Chlorodifluoromethane [75-45-6]	1000 ppm	—	A4	86.47	CVS
Chlorodiphenyl (42% chlorine) [53469-21-9]	1 mg/m^3	—	Skin	266.50	Irritation; chloracne; liver
Chlorodiphenyl (54% chlorine) [11097-69-1]	0.5 mg/m^3	—	Skin; A3	328.40	Irritation; chloracne; liver
Chloroform [67-66-3]	10 ppm	—	A3	119.38	Liver; reproductive
bis(Chloromethyl) ether [542-88-1]	0.001 ppm	—	A1	114.96	Cancer (lung)
Chloromethyl methyl ether [107-30-2]	—(L)	—	A2	80.50	Cancer (lung); irritation
1-Chloro-1-nitropropane [600-25-9]	2 ppm	—	—	123.54	Irritation; liver; lung
Chloropentafluoroethane [76-15-3]	1000 ppm	—	—	154.47	CVS
Chloropicrin [76-06-2]	0.1 ppm	—	A4	164.39	Irritation; lung
β-Chloroprene [126-99-8]	10 ppm	—	Skin	88.54	Irritation; liver; reproductive
2-Chloropropionic acid [598-78-7]	0.1 ppm	—	Skin	108.53	Irritation; reproductive
o-Chlorostyrene [2039-87-4]	50 ppm	75 ppm	—	138.60	Kkidney; CNS; neurotoxic; liver
o-Chlorotoluene [95-49-8]	50 ppm	—	—	126.59	Irritation
‡ Chlorpyrifos [2921-88-2]	(0.2 mg/m^3)	—	Skin; A4; BEI	350.57	Cholinergic
Chromite ore processing (Chromate), as Cr	0.05 mg/m^3	—	A1	—	Cancer (lung)
Chromium [7440-47-3] and inorganic compounds, as Cr					
Metal and Cr III compounds	0.5 mg/m^3	—	A4	Varies	Irritation; dermatitis
Water-soluble Cr VI compounds	0.05 mg/m^3	—	A1; BEI	Varies	Liver; kidney; respiratory
Insoluble Cr VI compounds	0.01 mg/m^3	—	A1	Varies	Cancer; irritation
Chromyl chloride [14977-61-8]	0.025 ppm	—	—	154.92	Kidney; liver; respiratory
Chrysene [218-01-9]	—(L)	—	A3	228.30	Skin
Clopidol [2971-90-6]	10 mg/m^3	—	A4	192.06	Irritation
Coal dust					
Anthracite	0.4 mg/m^3 (R)	—	A4	—	Lung fibrosis; lung function
Bituminous	0.9 mg/m^3 (R)	—	A4	—	Lung fibrosis; lung
Coal tar pitch volatiles [65996-93-2], as benzene soluble aerosol	0.2 mg/m^3	—	A1	—	Cancer
Cobalt [7440-48-4], and inorganic compounds, as Co	0.02 mg/m^3	—	A3; BEI	58.93 Varies	Asthma; lung; CVS

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Cobalt carbonyl [10210-68-1], as Co	0.1 mg/m^3	—	—	341.94	Lung edema
Cobalt hydrocarbonyl [16842-03-8], as Co	0.1 mg/m^3	—	—	171.98	Lung edema
Copper [7440-50-8]				63.55	Irritation; GI; metal fume fever
Fume	0.2 mg/m^3	—	—		
Dusts and mists, as Cu	1 mg/m^3	—	—		
Cotton dust, raw	0.2 mg/m^3 (G)	—	—	—	Lung; byssinosis
Cresol, all isomers [1319-77-3; 95-48-7; 108-39-4; 106-44-5]	5 ppm	—	Skin	108.14	Dermatitis; irritation; CNS
Crotonaldehyde [4170-30-3]	—	C 0.3 ppm	Skin; A3	70.09	Irritation
Crufomate [299-85-5]	5 mg/m^3	—	A4; BEI	291.71	Cholinergic
Cumene [98-82-8]	50 ppm	—	—	120.19	Irritation; CNS
Cyanamide [420-04-2]	2 mg/m^3	—	—	42.04	Irritation
Cyanogen [460-19-5]	10 ppm	—	—	52.04	Irritation
Cyanogen chloride [506-77-4]	—	C 0.3 ppm	—	61.48	Irritation; lung function
‡ Cyclohexane [110-82-7]	(300 ppm)	—	—	84.16	Irritation
Cyclohexanol [108-93-0]	50 ppm	—	Skin	100.16	Irritation; CNS
Cyclohexanone [108-94-1]	25 ppm	—	Skin; A4	94.18	Irritation; liver
Cyclohexene [110-83-8]	300 ppm	—	—	82.14	Irritation
Cyclohexylamine [108-91-8]	10 ppm	—	A4	99.17	Irritation
Cyclonite [121-82-4]	0.5 mg/m^3	—	Skin; A4	222.26	Irritation; CNS; liver; blood
Cyclopentadiene [542-92-7]	75 ppm	—	—	66.10	Irritation
Cyclopentane [287-92-3]	600 ppm	—	—	70.13	Irritation; narcosis
Cyhexatin [13121-70-5]	5 mg/m^3	—	A4	385.16	Irritation
2,4-D [94-75-7]	10 mg/m^3	—	A4	221.04	Irritation
DDT (Dichlorodiphenyltrichloroethane) [50-29-3]	1 mg/m^3	—	A3	354.50	Seizures; liver
Decaborane [17702-41-9]	0.05 ppm	0.15 ppm	Skin	122.31	CNS; lung function
‡ Demeton [8065-48-3]	(0.01 ppm)	—	Skin; BEI	258.34	Cholinergic
Diacetone alcohol [123-42-2]	50 ppm	—	—	116.16	Irritation
‡ Diazinon [333-41-5]	(0.1 mg/m^3)	—	Skin; A4; BEI	304.36	Cholinergic
Diazomethane [334-88-3]	0.2 ppm	—	A2	42.04	Irritation; cancer (lung)
Diborane [19287-45-7]	0.1 ppm	—	—	27.69	CNS; lung function
2-N-Dibutylaminoethanol [102-81-8]	0.5 ppm	—	Skin	173.29	Irritation; cholinergic
Dibutyl phenyl phosphate [2528-36-1]	0.3 ppm	—	Skin; BEI	286.26	Irritation; cholinergic

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Dibutyl phosphate [107-66-4]	1 ppm	2 ppm	—	210.21	Irritation
Dibutyl phthalate [84-74-2]	5 mg/m^3	—	—	278.34	Reproductive; irritation
Dichloroacetylene [7572-29-4]	—	C 0.1 ppm	A3	94.93	GI; neurotoxicity; irritation
o-Dichlorobenzene [95-50-1]	25 ppm	50 ppm	A4	147.01	Irritation; liver
p-Dichlorobenzene [106-46-7]	10 ppm	—	A3	147.01	Irritation; kidney
3,3_-Dichlorobenzidine [91-94-1]	—	—	Skin; A3	253.13	Irritation; dermatitis
1,4-Dichloro-2-butene [764-41-0]	0.005 ppm	—	Skin; A2	124.99	Cancer; irritation
Dichlorodifluoromethane [75-71-8]	1000 ppm	—	A4	98.97	CVS
1,3-Dichloro-5,5-dimethyl hydantoin [118-52-5]	0.2 mg/m^3	0.4 mg/m^3	—	197.03	Irritation
1,1-Dichloroethane [75-34-3]	100 ppm	—	A4	98.97	Liver; kidney; irritation
1,2-Dichloroethylene, all isomers [540-59-0; 156-59-2; 156-60-5]	200 ppm	—	—	96.95	Liver
Dichloroethyl ether [111-44-4]	5 ppm	10 ppm	Skin; A4	143.02	Irritation; lung
Dichlorofluoromethane [75-43-4]	10 ppm	—	—	102.92	Liver
Dichloromethane [75-09-2]	50 ppm	—	A3; BEI	84.93	CNS; anoxia
1,1-Dichloro-1-nitroethane [594-72-9]	2 ppm	—	—	143.96	Irritation
1,3-Dichloropropene [542-75-6]	1 ppm	—	Skin; A3	110.98	Irritation
2,2-Dichloropropionic acid [75-99-0]	5 mg/m^3(I)	—	A4	142.97	Irritation
Dichlorotetrafluoroethane [76-14-2]	1000 ppm	—	A4	170.93	CVS; narcosis; asphyxiation
‡ Dichlorvos [62-73-7]	(0.9 mg/m^3)	—	Skin; (—);A4; BEI	220.98	Cholinergic
‡ Dicrotophos [141-66-2]	(0.25 mg/m^3)	—	Skin; A4; BEI	237.21	Cholinergic
Dicyclopentadiene [77-73-6]	5 ppm	—	—	132.21	Irritation
Dicyclopentadienyl iron [102-54-5]	10 mg/m^3	—	—	186.03	Blood; liver
Dieldrin [60-57-1]	0.25 mg/m^3	—	Skin; A4	380.93	Liver; CNS
Diethanolamine [111-42-2]	2 mg/m^3	—	Skin	105.14	Liver; kidney; blood
Diethylamine [109-89-7]	5 ppm	15 ppm	Skin; A4	73.14	Irritation
2-Diethylaminoethanol [100-37-8]	2 ppm	—	Skin	117.19	Irritation; CNS
Diethylene triamine [111-40-0]	1 ppm	—	Skin	103.17	Irritation; sensitization
Di(2-ethylhexyl)phthalate (DEHP) [117-81-7]	5 mg/m^3	—	A3	390.54	Irritation
Diethyl ketone [96-22-0]	200 ppm	300 ppm	—	86.13	Irritation; narcosis
Diethyl phthalate [84-66-2]	5 mg/m^3	—	A4	222.23	Irritation
Difluorodibromomethane [75-61-6]	100 ppm	—	—	209.83	Irritation; liver; CNS
Diglycidyl ether (DGE) [2238-07-5]	0.1 ppm	—	A4	130.14	Irritation; reproductive; blood
Diisobutyl ketone [108-83-8]	25 ppm	—	—	142.23	Irritation
Diisopropylamine [108-18-9]	5 ppm	—	Skin	101.19	Vision; irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
N,N-Dimethylacetamide [127-19-5]	10 ppm	—	Skin; BEI	87.12	Reproductive; liver
Dimethylamine [124-40-3]	5 ppm	15 ppm	A4	45.08	Irritation
Dimethylaniline (N,N-Dimethylaniline) [121-69-7]	5 ppm	10 ppm	Skin; A4; BEI	121.18	Anoxia; neurotoxicity
Dimethyl carbamoyl chloride [79-44-7]	—(L)	—	A2	107.54	Cancer (lung)
Dimethylethoxysilane [14857-34-2]	0.5 ppm	1.5 ppm	—	104.20	Irritation; headache
Dimethylformamide [68-12-2]	10 ppm	—	Skin, A4; BEI	73.09	Liver
1,1-Dimethylhydrazine [57-14-7]	0.01 ppm	—	Skin; A3	60.12	Irritation; neoplasia
Dimethylphthalate [131-11-3]	5 mg/m^3	—	—	194.19	Irritation
Dimethyl sulfate [77-78-1]	0.1 ppm	—	Skin; A3	126.10	Irritation
Dinitolmide [148-01-6]	5 mg/m^3	—	A4	225.16	Irritation; liver
Dinitrobenzene, all isomers [528-29-0; 99-65-0; 100-25-4]	0.15 ppm	—	Skin; BEI	168.11	Anoxia
Dinitrol-o-cresol [534-52-1]	0.2 mg/m^3	—	Skin	198.13	Metabolic disorders
Dinitrotoluene [25321-14-6]	0.2 mg/m^3	—	Skin; A3; BEI	182.15	CVS; reproductive
1,4-Dioxane [123-91-1]	20 ppm	—	Skin; A3	88.10	Irritation; liver; kidney
‡ Dioxathion [78-34-2]	(0.2 mg/m^3)	—	Skin; A4; BEI	456.54	Cholinergic
Diphenylamine [122-39-4]	10 mg/m^3	—	A4	169.24	Liver; kidney; blood
Dipropylene glycol methyl ether [34590-94-8]	100 ppm	150 ppm	Skin	148.20	Irritation; CNS
Dipropyl ketone [123-19-3]	50 ppm	—	—	114.80	Irritation; liver; kidney; neurotoxicity
Diquat [2764-72-9]	0.5 mg/m^3(I)	—	Skin; A4	344.07	Irritation; eye
	0.1 mg/m^3 (R)	—	Skin; A4		Irritation; eye
Disulfiram [97-77-8]	2 mg/m^3	—	A4	296.54	GI; CVS
‡ Disulfoton [298-04-4]	(0.1 mg/m^3)	—	Skin; (—);BEI	274.38	Cholinergic
Diuron [330-54-1]	10 mg/m^3	—	A4	233.10	Irritation; blood
Divinyl benzene [1321-74-0]	10 ppm	—	—	130.19	Irritation
Emery [1302-74-5]	10 mg/m^3 (E)	—	—	—	Irritation
Endosulfan [115-29-7]	0.1 mg/m^3	—	Skin; A4	406.95	Liver; CNS
Endrin [72-20-8]	0.1 mg/m^3	—	Skin; A4	380.93	CNS; liver
Enflurane [13838-16-9]	75 ppm	—	A4	184.50	CNS; CVS
Epichlorohydrin [106-89-8]	0.5 ppm	—	Skin; A3	92.53	Irritation; liver; kidney
EPN [2104-64-5]	0.1 mg/m^3	—	Skin; A4; BEI	323.31	Cholinergic
Ethane [74-84-0]		Simple asphyxiant (D)		30.08	Asphyxiation
Ethanol [64-17-5]	1000 ppm	—	A4	46.07	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Ethanolamine [141-43-5]	3 ppm	6 ppm	—	61.08	Irritation
‡ Ethion [563-12-2]	(0.4 mg/m^3)	—	Skin; BEI	384.48	Cholinergic
2-Ethoxyethanol (EGEE) [110-80-5]	5 ppm	—	Skin; BEI	90.12	Reproductive
2-Ethoxyethyl acetate (EGEEA) [111-15-9]	5 ppm	—	Skin; BEI	132.16	Reproductive
Ethyl acetate [141-78-6]	400 ppm	—	—	88.10	Irritation
Ethyl acrylate [140-88-5]	5 ppm	15 ppm	A4	100.11	Irritation; cancer; sensitization
Ethylamine [75-04-7]	5 ppm	15 ppm	Skin	45.08	Irritation
Ethyl amyl ketone [541-85-5]	25 ppm	—	—	128.21	Irritation
‡ Ethyl benzene [100-41-4]	100 ppm	125 ppm	(—); BEI	106.16	Irritation; CNS
Ethyl bromide [74-96-4]	5 ppm	—	Skin; A3	108.98	Liver; kidney; CVS
Ethyl tert-butyl ether (ETBE) [637-92-3]	5 ppm	–	–	102.18	Irritation; lung function; reproductive
Ethyl butyl ketone [106-35-4]	50 ppm	75 ppm	—	114.19	Irritation; narcosis
Ethyl chloride [75-00-3]	100 ppm	—	Skin; A3	64.52	Liver; CNS
Ethyl cyanoacrylate [7085-85-0]	0.2 ppm	—	—	125.12	Irritation; necrosis
Ethylene [74-85-1]	Simple asphyxiant (D)		A4	28.00	Asphyxiation
Ethylene chlorohydrin [107-07-3]	—	C 1 ppm	Skin; A4	80.52	Irritation; liver; kidney; GI; CVS; CNS
Ethylenediamine [107-15-3]	10 ppm	—	Skin; A4	60.10	Irritation; asthma; sensitization
Ethylene dibromide [106-93-4]	—	—	Skin; A3	187.88	Irritation; liver; kidney
Ethylene dichloride [107-06-2]	10 ppm	—	A4	98.96	Liver; narcosis
Ethylene glycol [107-21-1]	—	C 100 mg/m^3 (H)	A4	62.07	Irritation
Ethylene glycol dinitrate (EGDN) [628-96-6]	0.05 ppm	—	Skin	152.06	CVS
Ethylene oxide [75-21-8]	1 ppm	—	A2	44.05	Cancer; reproductive
Ethylenimine [151-56-4]	0.5 ppm	—	Skin; A3	43.08	Irritation; bronchitis
Ethyl ether [60-29-7]	400 ppm	500 ppm	—	74.12	Irritation; narcosis
Ethyl formate [109-94-4]	100 ppm	—	—	74.08	Irritation
Ethylidene norbornene [16219-75-3]	—	C 5 ppm	—	120.19	Irritation
Ethyl mercaptan [75-08-1]	0.5 ppm	—	—	62.13	Irritation
N-Ethylmorpholine [100-74-3]	5 ppm	—	Skin	115.18	Irritation; ocular
Ethyl silicate [78-10-4]	10 ppm	—	—	208.30	Irritation; kidney
Fenamiphos [22224-92-6]	0.1 mg/m^3	—	Skin; A4; BEI	303.40	Cholinergic
Fensulfothion [115-90-2]	0.1 mg/m^3	—	A4; BEI	308.35	Cholinergic
Fenthion [55-38-9]	0.2 mg/m^3	—	Skin; A4; BEI	278.34	Cholinergic
Ferbam [14484-64-1]	10 mg/m^3	—	A4	416.50	Irritation
Ferrovanadium dust [12604-58-9]	1 mg/m^3	3 mg/m^3	—	—	Irritation
Flour dust	0.5 mg/m^3 (I)	–	SEN	NA	Asthma; lung function; bronchitis

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Fluorides, as F	2.5 mg/m^3	—	A4; BEI	Varies	Irritation; bone; fluorosis
Fluorine [7782-41-4]	1 ppm	2 ppm	—	38.00	Irritation
Fonofos [944-22-9]	0.1 mg/m^3	—	Skin; A4; BEI	246.32	Cholinergic
Formaldehyde [50-00-0]	—	C 0.3 ppm	SEN; A2	30.03	Irritation; cancer (nasal)
Formamide [75-12-7]	10 ppm	—	Skin	45.04	Irritation; liver
Formic acid [64-18-6]	5 ppm	10 ppm	—	46.02	Irritation
Furfural [98-01-1]	2 ppm	—	Skin; A3; BEI	96.08	Irritation
Furfuryl alcohol [98-00-0]	10 ppm	15 ppm	Skin	98.10	Irritation
Gasoline [8006-61-9]	300 ppm	500 ppm	A3	—	Irritation; CNS
Germanium tetrahydride [7782-65-2]	0.2 ppm	—	—	76.63	Blood
Glutaraldehyde [111-30-8], activated and Inactivated	—	C 0.05 ppm	A4; SEN	100.11	Irritation; sensitization
Glycerin mist [56-81-5]	10 mg/m^3	—	—	92.09	Irritation
Glycidol [556-52-5]	2 ppm	—	A3	74.08	Irritation; neoplasia
* Glyoxal [107-22-2]	0.1 mg/m^3 (I, V)	—	SEN; A4	58.04	Irritation
Grain dust (oat, wheat, barley)	4 mg/m^3 (E)	—	—	NA	Irritation; bronchitis; pulmonary function
Graphite (all forms except graphite fibers) [7782-42-5]	2 mg/m^3 (R)	—	—	—	Pneumoconiosis
Hafnium [7440-58-6] and compounds, as Hf	0.5 mg/m^3	—	—	178.49	Liver; irritation
Halothane [151-67-7]	50 ppm	—	A4	197.39	CNS; CVS; liver; reproductive
Helium [7440-59-7]		Simple asphyxiant (D)		4.00	Asphyxiation
Heptachlor [76-44-8] and Heptachlor epoxide [1024-57-3]	0.05 mg/m^3	—	Skin; A3	373.32 389.40	CNS; liver; blood
Heptane [142-82-5] (n-Heptane)	400 ppm	500 ppm	—	100.20	Irritation; narcosis
Hexachlorobenzene [118-74-1]	0.002 mg/m^3	—	Skin; A3	284.78	Liver; metabolic disorders
Hexachlorobutadiene [87-68-3]	0.02 ppm	—	Skin; A3	260.76	Irritation; kidney
Hexachlorocyclopentadiene [77-47-4]	0.01 ppm	—	A4	272.75	Irritation; pulmonary edema
Hexachloroethane [67-72-1]	1 ppm	—	Skin; A3	236.74	Irritation; liver; kidney
Hexachloronaphthalene [1335-87-1]	0.2 mg/m^3	—	Skin	334.74	Liver; chloracne
Hexafluoroacetone [684-16-2]	0.1 ppm	—	Skin	166.02	Reproductive; kidney
Hexamethylene diisocyanate [822-06-0]	0.005 ppm	—	—	168.22	Irritation; sensitization
Hexamethyl phosphoramide [680-31-9]	—	—	Skin; A3	179.20	Lung
n-Hexane [110-54-3]	50 ppm	—	Skin; BEI	86.18	Neuropathy; CNS; irritation
Hexane, Other isomers	500 ppm	1000 ppm	—	86.18	CNS; irritation
1,6-Hexanediamine [124-09-4]	0.5 ppm	—	—	116.21	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
‡ 1-Hexene [592-41-6]	(30 ppm)	—	—	84.16	CNS; irritation
sec-Hexyl acetate [108-84-9]	50 ppm	—	—	144.21	Irritation
Hexylene glycol [107-41-5]	—	C 25 ppm	—	118.17	Irritation
Hydrazine [302-01-2]	0.01 ppm	—	Skin; A3	32.05	Irritation; liver
Hydrogen [1333-74-0]		Simple asphyxiant (D)		1.01	Asphyxiation
Hydrogenated terphenyls (nonirradiated) [61788-32-7]	0.5 ppm	—	—	241.00	Irritation; liver
Hydrogen bromide [10035-10-6]	—	C 3 ppm	—	80.92	Irritation
Hydrogen chloride [7647-01-0]	—	C 5 ppm	—	36.47	Irritation; corrosion
Hydrogen cyanide and Cyanide salts, as CN					CNS; irritation; anoxia; lung; thyroid
Hydrogen cyanide [74-90-8]	—	C 4.7 ppm	Skin	27.03	
Cyanide salts	—	C 5 mg/m^3	Skin	Varies	
Hydrogen fluoride [7664-39-3], as F	—	C 3 ppm	BEI	20.01	Irritation; bone; teeth; fluorosis
Hydrogen peroxide [7722-84-1]	1 ppm	—	A3	34.02	Irritation; pulmonary edema; CNS
Hydrogen selenide [7783-07-5]	0.05 ppm	—	—	80.98	Irritation; GI
‡ Hydrogen sulfide [7783-06-4]	(10 ppm)	(15 ppm)	—	34.08	Irritation; CNS
Hydroquinone [123-31-9]	2 mg/m^3	—	A3	110.11	CNS; dermatitis; ocular
2-Hydroxypropyl acrylate [999-61-1]	0.5 ppm	—	Skin; SEN	130.14	Irritation; sensitization
Indene [95-13-6]	10 ppm	—	—	116.15	Irritation; liver; kidney
Indium [7440-74-6] and compounds, as In	0.1 mg/m^3	—	—	49.00	Pulmonary edema; bone; GI
Iodine [7553-56-2]	—	C 0.1 ppm	—	253.81	Irritation
Iodoform [75-47-8]	0.6 ppm	—	—	393.78	CNS; liver; kidney; CVS
Iron oxide dust & fume (Fe_2O_3) [1309-37-1], as Fe	5 mg/m^3	—	A4	159.70	Pneumoconiosis
Iron pentacarbonyl [13463-40-6]	0.1 ppm	0.2 ppm	—	195.90	Pulmonary edema; CNS
Iron salts, soluble, as Fe	1 mg/m^3	—	—	Varies	Irritation
Isoamyl alcohol [123-51-3]	100 ppm	125 ppm	—	88.15	Irritation
Isobutyl acetate [110-19-0]	150 ppm	—	—	116.16	Irritation
Isobutyl alcohol [78-83-1]	50 ppm	—	—	74.12	Irritation; ocular
Isooctyl alcohol [26952-21-6]	50 ppm	—	Skin	130.23	Irritation
Isophorone [78-59-1]	—	C 5 ppm	A3	138.21	Irritation; narcosis
Isophorone diisocyanate [4098-71-9]	0.005 ppm	—	—	222.30	Dermatitis; asthma; sensitization
‡ Isopropanol [67-63-0]	(400 ppm)	(500 ppm)	(—)	60.09	Irritation
2-Isopropoxyethanol [109-59-1]	25 ppm	—	Skin	104.15	Blood
‡ Isopropyl acetate [108-21-4]	(250 ppm)	(310 ppm)	—	102.13	Irritation
Isopropylamine [75-31-0]	5 ppm	10 ppm	—	59.08	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
N-Isopropylaniline [768-52-5]	2 ppm	—	Skin ; BEI	135.21	Blood
Isopropyl ether [108-20-3]	250 ppm	310 ppm	—	102.17	Irritation
Isopropyl glycidyl ether (IGE) [4016-14-2]	50 ppm	75 ppm	—	116.18	Irritation; dermatitis
Kaolin [1332-58-7]	2 mg/m^3 (E, R)	—	A4	—	Pneumoconiosis
Ketene [463-51-4]	0.5 ppm	1.5 ppm	—	42.04	Lung irritation; lung edema
Lead and inorganic compounds, as Pb	0.05 mg/m^3	—	A3; BEI	207.20 Varies	CNS; blood; kidney; reproductive
Lead arsenate [3687-31-8], as $Pb_3(AsO_4)_2$	0.15 mg/m^3	—	BEI	347.13	CNS; anemia; kidney; reproductive
Lead chromate [7758-97-6], as Pb , as Cr	0.05 mg/m^3 0.012 mg/m^3	— —	A2; BEI A2	323.22	Cancer; CVS; reproductive
Lindane [58-89-9]	0.5 mg/m^3	—	Skin; A3	290.85	CNS; liver
Lithium hydride [7580-67-8]	0.025 mg/m^3	—	—	7.95	Irritation
L.P.G. (Liquefied petroleum gas) [68476-85-7]	1000 ppm	—	—	42–58	Asphyxiation
Magnesite [546-93-0]	10 mg/m^3 (E)	—	—	84.33	Irritation; pneumoconiosis
Magnesium oxide fume [1309-48-4]	10 mg/m^3	—	—	40.32	Irritation; metal fume fever
Malathion [121-75-5]	10 mg/m^3	—	Skin; A4; BEI	330.36	Cholinergic; CNS; neuropathy; vision
Maleic anhydride [108-31-6]	0.1 ppm	—	SEN; A4	98.06	Irritation; asthma
Manganese [7439-96-5] and inorganic compounds, as Mn	0.2 mg/m^3	—	—	54.94 Varies	CNS (manganism); lung; reproductive
Manganese cyclopentadienyl tricarbonyl [12079-65-1], as Mn	0.1 mg/m^3	—	Skin	204.10	CNS; pulmonary edema
Mercury [7439-97-6], as Hg				200.59	
Alkyl compounds	0.01 mg/m^3	0.03 mg/m^3	Skin	Varies	CNS
Aryl compounds	0.1 mg/m^3	—	Skin	Varies	CNS; neuropathy; vision; kidney
Elemental and inorganic forms	0.025 mg/m^3	—	Skin; A4; BEI	Varies	CNS; kidney; reproductive
Mesityl oxide [141-79-7]	15 ppm	25 ppm	—	98.14	Irritation; narcosis; liver; kidney
Methacrylic acid [79-41-4]	20 ppm	—	—	86.09	Irritation
Methane [74-82-8]		Simple asphyxiant (D)		16.04	Asphyxiation
Methanol [67-56-1]	200 ppm	250 ppm	Skin; BEI	32.04	Neuropathy; vision; CNS
Methomyl [16752-77-5]	2.5 mg/m^3	—	A4; BEI	162.20	Cholinergic
Methoxychlor [72-43-5]	10 mg/m^3	—	A4	345.65	CNS; liver
2-Methoxyethanol (EGME) [109-86-4]	5 ppm	—	Skin; BEI	76.09	Blood; reproductive; CNS
2-Methoxyethyl acetate (EGMEA) [110-49-6]	5 ppm	—	Skin; BEI	118.13	Blood; reproductive; CNS
4-Methoxyphenol [150-76-5]	5 mg/m^3	—	—	124.15	Eye; depigmentation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
1-Methoxy-2-propanol (PGME) [107-98-2]	100 ppm	150 ppm	—	90.12	Irritation; anesthesia
bis-(2-Methoxypropyl) ether (DPGME) [34590-94-8]	100 ppm	150 ppm	Skin	148.20	Irritation; CNS
Methyl acetate [79-20-9]	200 ppm	250 ppm	—	78.04	Irritation; narcosis
Methyl acetylene [74-99-7]	1000 ppm	—	—	40.07	Anesthesia
Methyl acetylene-propadiene mixture (MAPP)	1000 ppm	1250 ppm	—	40.07	Anesthesia
Methyl acrylate [96-33-3]	2 ppm	—	Skin; SEN; A4	86.09	Irritation
Methylacrylonitrile [126-98-7]	1 ppm	—	Skin	67.09	Irritation; CNS
Methylal [109-87-5]	1000 ppm	—	—	76.10	Irritation; CNS
Methylamine [74-89-5]	5 ppm	15 ppm	—	31.06	Irritation
Methyl n-amyl ketone [110-43-0]	50 ppm	—	—	114.18	Irritation
N-Methyl aniline [100-61-8]	0.5 ppm	—	Skin; BEI	107.15	Anoxia; blood
Methyl bromide [74-83-9]	1 ppm	—	Skin; A4	94.95	Irritation
‡ Methyl tert-butyl ether (MTBE) [1634-04-4]	(40 ppm)	—	A3	88.17	Kidney; reproductive
Methyl n-butyl ketone [591-78-6]	5 ppm	10 ppm	Skin	100.16	Neuropathy
Methyl chloride [74-87-3]	50 ppm	100 ppm	Skin; A4	50.49	Kidney; CNS; reproductive
Methyl chloroform [71-55-6]	350 ppm	450 ppm	A4; BEI	133.42	Anesthesia; CNS
Methyl 2-cyanoacrylate [137-05-3]	0.2 ppm	—	—	111.10	Irritation; dermatitis
Methylcyclohexane [108-87-2]	400 ppm	—	—	98.19	Narcosis; irritation
Methylcyclohexanol [25639-42-3]	50 ppm	—	—	114.19	Irritation; narcosis; liver; kidney
o-Methylcyclohexanone [583-60-8]	50 ppm	75 ppm	Skin	112.17	Irritation; narcosis
2-Methylcyclopentadienyl manganese tricarbonyl [12108-13-3], as Mn	0.2 mg/m^3	—	Skin	218.10	CNS; liver; kidney
Methyl demeton [8022-00-2]	0.5 mg/m^3	—	Skin; BEI	230.30	Irritation; cholinergic
Methylene bisphenyl isocyanate (MDI) [101-68-8]	0.005 ppm	—	—	250.26	Irritation; lung edema; sensitization
4,4'-Methylene bis(2-chloroaniline) [MBOCA; MOCA®] [101-14-4]	0.01 ppm	—	Skin; A2; BEI	267.17	Anoxia; kidney; cancer (bladder)
Methylene bis(4-cyclohexylisocyanate) [5124-30-1]	0.005 ppm	—	—	262.35	Irritation; sensitization
4,4'-Methylene dianiline [101-77-9]	0.1 ppm	—	Skin; A3	198.26	Liver
Methyl ethyl ketone (MEK) [78-93-3]	200 ppm	300 ppm	BEI	72.10	Irritation; CNS
Methyl ethyl ketone peroxide [1338-23-4]	—	C 0.2 ppm	—	176.24	Irritation; liver; kidney
Methyl formate [107-31-3]	100 ppm	150 ppm	—	65.05	Irritation; narcosis.; lung edema
Methyl hydrazine [60-34-4]	0.01 ppm	—	Skin; A3	46.07	Irritation; liver
Methyl iodide [74-88-4]	2 ppm	—	Skin	141.95	CNS; irritation
Methyl isoamyl ketone [110-12-3]	50 ppm	—	—	114.20	Irritation; narcosis; liver; kidney
Methyl isobutyl carbinol [108-11-2]	25 ppm	40 ppm	Skin	102.18	Irritation; anesthesia
Methyl isobutyl ketone [108-10-1]	50 ppm	75 ppm	BEI	100.16	Irritation; kidney

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Methyl isocyanate [624-83-9]	0.02 ppm	—	Skin	57.05	Irritation; lung edema; sensitization
Methyl isopropyl ketone [563-80-4]	200 ppm	—	—	86.14	Irritation
Methyl mercaptan [74-93-1]	0.5 ppm	—	—	48.11	Irritation; CNS
Methyl methacrylate [80-62-6]	50 ppm	100 ppm	SEN; A4	100.13	Irritation; dermatitis
Methyl parathion [298-00-0]	0.2 mg/m^3	—	Skin; A4; BEI	263.23	Cholinergic
Methyl propyl ketone [107-87-9]	200 ppm	250 ppm	—	86.17	Irritation; narcosis
Methyl silicate [681-84-5]	1 ppm	—	—	152.22	Eye; lung
α-Methyl styrene [98-83-9]	50 ppm	100 ppm	—	118.18	Irritation; dermatitis; CNS
Methyl vinyl ketone [78-94-4]	—	C 0.2 ppm	Skin; SEN	70.10	Irritation; sensitization
Metribuzin [21087-64-9]	5 mg/m^3	—	A4	214.28	Blood; liver
‡ Mevinphos [7786-34-7]	(0.09 mg/m^3)	(0.27 mg/m^3)	Skin; (—); BEI	224.16	Cholinergic
Mica [12001-26-2]	3 mg/m^3 (R)	—	—	—	Pneumoconiosis
‡ Molybdenum [7439-98-7], as Mo				95.95	
* Metal and Insoluble compounds	3 mg/m^3 (R)	—	—		Lung; CNS
‡* Soluble compounds	0.5 mg/m^3 (R)	—	(A3)		Lung; irritation
‡ Monocrotophos [6923-22-4]	(0.25 mg/m^3)	—	Skin; A4; BEI	223.16	Cholinergic
Morpholine [110-91-8]	20 ppm	—	Skin; A4	87.12	Irritation; vision
‡ Naled [300-76-5]	(3 mg/m^3)	—	Skin; (—);A4; BEI	380.79	Cholinergic; dermatitis
Naphthalene [91-20-3]	10 ppm	15 ppm	A4	128.19	Irritation; ocular; blood
α-Naphthylamine [91-59-8]	— (L)	—	A1	143.18	Cancer (bladder)
Neon [7440-01-9]		Simple asphyxiant (D)		20.18	Asphyxiation
Nickel, as Ni					
Elemental [7440-02-0]	1.5 mg/m^3 (I)	—	A5	58.71	Dermatitis; pneumoconiosis
Soluble compounds (NOS)	0.1 mg/m^3 (I)	—	A4	Varies	CNS; irritation; dermatitis
Insoluble compounds (NOS)	0.2 mg/m^3 (I)	—	A1	Varies	Cancer; irritation; dermatitis
Nickel subsulfide [12035-72-2]	0.1 mg/m^3 (I)	—	A1	240.19	Cancer; irritation; dermatitis
Nickel carbonyl [13463-39-3], as Ni	0.05 ppm	—	—	170.73	Irritation; CNS
Nicotine [54-11-5]	0.5 mg/m^3	—	Skin	162.23	CVS; GI; CNS
Nitrapyrin [1929-82-4]	10 mg/m^3	20 mg/m^3	A4	230.93	Liver
Nitric acid [7697-37-2]	2 ppm	4 ppm	—	63.02	Irritation; corrosion; pulmonary edema
Nitric oxide [10102-43-9]	25 ppm	—	BEI	30.01	Anoxia; irritation; cyanosis
p-Nitroaniline [100-01-6]	3 mg/m^3	—	Skin; A4; BEI	138.12	Anoxia; anemia; liver
Nitrobenzene [98-95-3]	1 ppm	—	Skin; A3; BEI	123.11	Anoxia

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
p-Nitrochlorobenzene [100-00-5]	0.1 ppm	—	Skin; A3; BEI	157.56	Anoxia; blood; liver
4-Nitrodiphenyl [92-93-3]	—	—	Skin; A2	199.20	Cancer (bladder)
Nitroethane [79-24-3]	100 ppm	—	—	75.07	Irritation; narcosis; liver
Nitrogen [7727-37-9]		Simple asphyxiant (D)		14.01	Asphyxiation
Nitrogen dioxide [10102-44-0]	3 ppm	5 ppm	A4	46.01	Irritation; pulmonary edema
Nitrogen trifluoride [7783-54-2]	10 ppm	—	BEI	71.00	Anoxia; blood; liver; kidney
Nitroglycerin (NG) [55-63-0]	0.05 ppm	—	Skin	227.09	CVS
Nitromethane [75-52-5]	20 ppm	—	A3	61.04	Thyroid
1-Nitropropane [108-03-2]	25 ppm	—	A4	89.09	Irritation; liver
2-Nitropropane [79-46-9]	10 ppm	—	A3	89.09	Liver; cancer
N-Nitrosodimethylamine [62-75-9]	—(L)	—	Skin; A3	74.08	Liver
Nitrotoluene, all isomers [88-72-2; 99-08-1; 99-99-0]	2 ppm	—	Skin; BEI	137.13	Anoxia; cyanosis
Nitrous oxide [10024-97-2]	50 ppm	—	A4	44.02	Reproductive; blood; CNS
Nonane [111-84-2], all isomers	200 ppm	—	—	128.26	CNS; skin; irritation
Octachloronaphthalene [2234-13-1]	0.1 mg/m^3	0.3 mg/m^3	Skin	403.74	Liver; dermatitis
Octane, all isomers [111-65-9]	300 ppm	—	—	114.22	Irritation
‡ Oil mist, mineral	(5 mg/m^3) (P)	(10 mg/m^3)	(—)	—	Lung
Osmium tetroxide [20816-12-0]	0.0002 ppm	0.0006 ppm	—	254.20	Irritation; vision
Oxalic acid [144-62-7]	1 mg/m^3	2 mg/m^3	—	90.04	Irritation; burns
p,p'-Oxybis(benzenesulfonyl hydrazide) [80-51-3]	0.1 mg/m^3 (I)	—	—	326.00	Irritation
Oxygen difluoride [7783-41-7]	—	C 0.05 ppm	—	54.00	Irritation; kidney
Ozone [10028-15-6]				48	Lung function; irritation
Heavy work	0.05 ppm	—	A4		
Moderate work	0.08 ppm	—	A4		
Light work	0.1 ppm	—	A4		
Heavy, moderate, or light workloads (≤ 2 hours)	0.2 ppm	—	A4		
Paraffin wax fume [8002-74-2]	2 mg/m^3	—	—	—	Irritation
Paraquat [4685-14-7]	0.5 mg/m^3	—	—	257.18	Lung; irritation
	0.1 mg/m^3 (R)	—	—		
‡ Parathion [56-38-2]	(0.1 mg/m^3)	—	Skin; A4; BEI	291.27	Cholinergic
Particulates (Insoluble) Not Otherwise Specified (PNOS)	10 mg/m^3 (E, I)	—	—	—	Lung
	3 mg/m^3 (E, R)	—	—	—	Lung
Pentaborane [19624-22-7]	0.005 ppm	0.015 ppm	—	63.17	CNS
Pentachloronaphthalene [1321-64-8]	0.5 mg/m^3	—	Skin	300.40	Chloracne; liver

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Pentachloronitrobenzene [82-68-8]	0.5 mg/m^3	—	A4	295.36	Liver
Pentachlorophenol [87-86-5]	0.5 mg/m^3	—	Skin; A3; BEI	266.35	CVS; CNS
Pentaerythritol [115-77-5]	10 mg/m^3	—	—	136.15	Irritation
Pentane, all isomers [78-78-4; 109-66-0; 463-82-1]	600 ppm	—	—	72.15	Irritation; narcosis
Pentyl acetate, all isomers [628-63-7; 626-38-0; 123-92-2; 625-16-1; 624-41-9; 620-11-1]	50 ppm	100 ppm	—	130.20	Irritation
Perchloromethyl mercaptan [594-42-3]	0.1 ppm	—	—	185.87	Irritation; pulmonary edema
Perchloryl fluoride [7616-94-6]	3 ppm	6 ppm	—	102.46	Irritation; blood
Perfluoroisobutylene [382-21-8]	—	C 0.01 ppm	—	200.04	Irritation; pulmonary edema
Perlite [93763-70-3]	10 mg/m^3 (E)	—	A4	—	Irritation
Persulfates, as persulfate	0.1 mg/m^3	—	—	Varies	Irritation
Phenol [108-95-2]	5 ppm	—	Skin; A4; BEI	94.11	Irritation; CNS; blood
Phenothiazine [92-84-2]	5 mg/m^3	—	Skin	199.26	Irritation; ocular; liver; kidney
N-Phenyl-beta-naphthylamine [135-88-6]	—	—	A4	219.29	Irritation
o-Phenylenediamine [95-54-5]	0.1 mg/m^3	—	A3	108.05	Irritation; liver; blood
m-Phenylenediamine [108-45-2]	0.1 mg/m^3	—	A4	108.05	Irritation; liver
p-Phenylenediamine [106-50-3]	0.1 mg/m^3	—	A4	108.05	Sensitization; skin; eye
Phenyl ether [101-84-8], vapor	1 ppm	2 ppm	—	170.20	Irritation; nausea
Phenyl glycidyl ether (PGE) [122-60-1]	0.1 ppm	—	Skin; SEN; A3	150.17	Irritation; dermatitis; sensitization
Phenylhydrazine [100-63-0]	0.1 ppm	—	Skin; A3	108.14	Dermatitis; anemia
Phenyl mercaptan [108-98-5]	0.5 ppm	—	—	110.18	Irritation; dermatitis
Phenylphosphine [638-21-1]	—	C 0.05 ppm	—	110.10	Irritation; dermatitis; blood; reproductive
Phorate [298-02-2]	0.05 mg/m^3	0.2 mg/m^3	Skin; BEI	260.40	Cholinergic
Phosgene [75-44-5]	0.1 ppm	—	—	98.92	Irritation; anoxia; lung edema
Phosphine [7803-51-2]	0.3 ppm	1 ppm	—	34.00	Irritation; CNS; GI
Phosphoric acid [7664-38-2]	1 mg/m^3	3 mg/m^3	—	98.00	Irritation
Phosphorus (yellow) [7723-14-0]	0.02 ppm	—	—	123.92	Irritation; liver; kidney; CVS; GI
Phosphorus oxychloride [10025-87-3]	0.1 ppm	—	—	153.35	Irritation; kidney
Phosphorus pentachloride [10026-13-8]	0.1 ppm	—	—	208.24	Irritation
Phosphorus pentasulfide [1314-80-3]	1 mg/m^3	3 mg/m^3	—	222.29	Irritation
Phosphorus trichloride [7719-12-2]	0.2 ppm	0.5 ppm	—	137.35	Irritation
Phthalic anhydride [85-44-9]	1 ppm	—	SEN; A4	148.11	Irritation; sensitization
m-Phthalodinitrile [626-17-5]	5 mg/m^3	—	—	128.14	Irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Picloram [1918-02-1]	10 mg/m^3	—	A4	241.48	Liver; kidney
Picric acid [88-89-1]	0.1 mg/m^3	—	—	229.11	Dermatitis; irritation; ocular; sensitization
Pindone [83-26-1]	0.1 mg/m^3	—	—	230.25	Liver; kidney; bleeding; dermatitis
Piperazine dihydrochloride [142-64-3]	5 mg/m^3	—	—	159.05	Irritation; burns; asthma; sensitization
Platinum [7440-06-4], Metal	1 mg/m^3	—	—	195.09	Irritation
Soluble salts, as Pt	0.002 mg/m^3	—	—	Varies	Asthma; irritation; sensitization
Polytetrafluoroethylene decomposition products	—(L)	B1	—	—	Pulmonary edema
Portland cement [65997-15-1]	10 mg/m^3 (E)	—	—	—	Irritation; dermatitis
Potassium hydroxide [1310-58-3]	—	C 2 mg/m^3	—	56.10	Irritation; corrosion
Propane [74-98-6]	2500 ppm	—	—	44.09	Asphyxiation
Propane sultone [1120-71-4]	—(L)	—	A3	122.14	Neoplasia
‡ n-Propanol (n-Propyl alcohol) [71-23-8]	200 ppm	250 ppm	(Skin); (—)	60.09	Irritation; narcosis
Propargyl alcohol [107-19-7]	1 ppm	—	Skin	56.06	Irritation; liver; kidney
β-Propiolactone [57-57-8]	0.5 ppm	—	A3	72.06	Irritation
Propionic acid [79-09-4]	10 ppm	—	—	74.08	Irritation
Propoxur [114-26-1]	0.5 mg/m^3	—	A3	209.24	Cholinergic
n-Propyl acetate [109-60-4]	200 ppm	250 ppm	—	102.13	Irritation
‡ Propylene [115-07-1]		(Simple asphyxiant (D))		42.08	(Asphyxiation)
Propylene dichloride [78-87-5]	75 ppm	110 ppm	A4	112.99	Irritation; CNS; liver; kidney
Propylene glycol dinitrate [6423-43-4]	0.05 ppm	—	Skin; BEI	166.09	CVS; headache; CNS, anoxia
Propylene imine [75-55-8]	2 ppm	—	Skin; A3	57.09	Irritation; CNS
* Propylene oxide [75-56-9]	2 ppm	—	SEN; A3	58.08	Irritation; cancer (nasal)
n-Propyl nitrate [627-13-4]	25 ppm	40 ppm	BEI	105.09	Blood; cyanosis; anoxia
Pyrethrum [8003-34-7]	5 mg/m^3	—	A4	345 (avg.)	Dermatitis; CNS; liver; sensitization
Pyridine [110-86-1]	5 ppm	—	—	70.10	Irritation; CNS; liver; kidney; blood
Quinone [106-51-4]	0.1 ppm	—	—	108.09	Irritation; eyes
Resorcinol [108-46-3]	10 ppm	20 ppm	A4	110.11	Irritation; dermatitis; blood
Rhodium [7440-16-6], as Rh				102.91	
Metal and insoluble compounds	1 mg/m^3	—	A4	Varies	Irritation
Soluble compounds, as Rh	0.01 mg/m^3	—	A4	Varies	Irritation
Ronnel [299-84-3]	10 mg/m^3	—	A4; BEI	321.57	Cholinergic

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Rosin core solder thermal decomposition products (colophony) [8050-09-7]	—(L)		SEN	NA	Irritation; asthma; sensitization
Rotenone (commercial) [83-79-4]	5 mg/m^3	—	A4	391.41	Irritation; CNS
Rouge	10 mg/m^3 (E)	—	A4	159.70	Lung; siderosis; irritation
Rubber solvent (Naphtha) [8030-30-6]	400 ppm	—	—	97(mean)	Irritation; CNS
Selenium [7782-49-2] and compounds, as Se	0.2 mg/m^3	—	—	78.96	Irritation
Selenium hexafluoride [7783-79-1]	0.05 ppm	—	—	192.96	Pulmonary edema
Sesone [136-78-7]	10 mg/m^3	—	A4	309.13	Irritation
Silica, Amorphous — Diatomaceous earth (uncalcined) [61790-53-2]	10 mg/m^3 (E, I) 3 mg/m^3 (E, R)	— —	— —	—	Irritation; pneumoconiosis
Precipitated silica and silica gel [112926-00-8]	10 mg/m^3	—	—	—	Irritation
Silica fume [69012-64-2]	2 mg/m^3 (R)	—	—	—	Irritation; fever
Silica, fused [60676-86-0]	0.1 mg/m^3 (R)	—	—	60.08	Lung fibrosis
Silica, Crystalline — Cristobalite [14464-46-1]	0.05 mg/m^3 (R)	—	—	60.08	Lung fibrosis; silicosis
Quartz [14808-60-7]	0.05 mg/m^3) (R)	—	A2	60.08	Silicosis; lung function; lung fibrosis; cancer
Tridymite [15468-32-3]	0.05 mg/m^3 (R)	—	—	60.08	Lung fibrosis; silicosis
Tripoli [1317-95-9], as quartz	0.1 mg/m^3 (R)	—		—	Lung fibrosis
Silicon [7440-21-3]	10 mg/m^3	—	—	28.09	Lung
‡ Silicon carbide [409-21-2]	(10 mg/m^3 (E))	—	(A4)	40.10	Lung
Silicon tetrahydride [7803-62-5]	5 ppm	—	—	32.12	Irritation
Silver [7440-22-4], Metal Soluble compounds, as Ag	0.1 mg/m^3 0.01 mg/m^3	— —	— —	107.87 Varies	Argyria (skin, eyes, mucosa)
Soapstone	6 mg/m^3 (E) 3 mg/m^3 (E, R)	— —	— —	—	Pneumoconiosis
Sodium azide [26628-22-8] as Sodium azide as Hydrazoic acid vapor	 — —	 C 0.29 mg/m^3 C 0.11 ppm	 A4 A4	65.02	CNS; CVS; lung
Sodium bisulfite [7631-90-5]	5 mg/m^3	—	A4	104.07	Irritation
Sodium fluoroacetate [62-74-8]	0.05 mg/m^3	—	Skin	100.02	CNS; CVS

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Sodium hydroxide [1310-73-2]					
Sodium metabisulfite [7681-57-4]	5 mg/m^3	—	A4	190.13	Irritation
Starch [9005-25-8]	10 mg/m^3	—	A4	—	Dermatitis; lung
Stearates[J]	10 mg/m^3	—	A4	Varies	Irritation
Stoddard solvent [8052-41-3]	100 ppm	—	—	140.00	Irritation; narcosis; kidney
Strontium chromate [7789-06-2], as Cr	0.0005 mg/m^3	—	A2	203.61	Cancer (lung)
Strychnine [57-24-9]	0.15 mg/m^3	—	—	334.40	CNS
Styrene, monomer [100-42-5]	20 ppm	40 ppm	A4; BEI	104.16	Neurotoxicity; irritation; CNS
Subtilisins [1395-21-7; 9014-01-1], as crystalline active enzyme	—	C 0.00006 mg/m^3	—	—	Irritation; lung; sensitization
Sucrose [57-50-1]	10 mg/m^3	—	A4	342.30	Lung
Sulfometuron methyl [74222-97-2]	5 mg/m^3	—	A4	364.38	Irritation; blood
Sulfotep [3689-24-5]	0.2 mg/m^3	—	Skin; A4; BEI	322.30	Cholinergic
Sulfur dioxide [7446-09-5]	2 ppm	5 ppm	A4	64.07	Irritation
Sulfur hexafluoride [2551-62-4]	1000 ppm	—	—	146.07	Asphyxiation
‡ Sulfuric acid [7664-93-9]	(1 mg/m^3)	(3 mg/m^3)	A2[M]	98.08	Irritation; cancer (larnyx)
Sulfur monochloride [10025-67-9]	—	C 1 ppm	—	135.03	Irritation
Sulfur pentafluoride [5714-22-7]	—	C 0.01 ppm	—	254.11	Irritation
Sulfur tetrafluoride [7783-60-0]	—	C 0.1 ppm	—	108.07	Irritation
Sulfuryl fluoride [2699-79-8]	5 ppm	10 ppm	—	102.07	Irritation; CNS
Sulprofos [35400-43-2]	1 mg/m^3	—	A4; BEI	322.43	Cholinergic
Synthetic Vitreous Fibers					
Continuous filament glass fibers	1 f/cc [F]	—	A4	—	Irritation
Continuous filament glass fibers	5 mg/m^3 [I]	—	A4	—	Irritation
Glass wool fibers	1 f/cc [F]	—	A3	—	Irritation;lung
Rock wool fibers	1 f/cc [F]	—	A3	—	Irritation; lung
Slag wool fibers	1 f/cc [F]	—	A3	—	Irritation; lung
Special purpose glass fibers	0.2 f/cc [F]	—	A3	—	Irritation; lung
*Refractory ceramic fibers		—	A2	—	Pulmonary fibrosis; cancer
2,4,5-T [93-76-5]	10 mg/m^3	—	A4	255.49	Irritation
Talc [14807-96-6]					
Containing no asbestos fibers	2 mg/m^3 [E, R]	—	A4	—	Lung
Containing asbestos fibers	Use asbestos TLV [E, R]	—	A1	—	Asbestosis; cancer

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Tantalum metal [7440-25-7] and				180.95	Irritation; lung
oxide [1314-61-0] dusts, as Ta	5 mg/m^3	—	—	441.90	Irritation; lung
Tellurium [13494-80-9] and compounds (NOS), as Te	0.1 mg/m^3	—	—	127.60 Varies	CNS; cyanosis; liver
Tellurium hexafluoride [7783-80-4]	0.02 ppm	—	—	241.61	Irritation
Temephos [3383-96-8]	10 mg/m^3	—	BEI	466.46	Cholinergic
TEPP [107-49-3]	0.05 mg/m^3	—	Skin; BEI	290.20	Cholinergic
Terephthalic acid [100-21-0]	10 mg/m^3	—	—	166.13	Lung; urinary
Terphenyls [26140-60-3]	—	C 5 mg/m^3	—	230.31	Irritation
1,1,1,2-Tetrachloro-2,2-difluoroethane [76-11-9]	500 ppm	—	—	203.83	Liver; blood
1,1,2,2-Tetrachloro-1,2-difluoroethane [76-12-0]	500 ppm	—	—	203.83	CNS; pulmonary edema
1,1,2,2-Tetrachloroethane [79-34-5]	1 ppm	—	Skin; A3	167.86	Liver; CNS; GI
Tetrachloroethylene [127-18-4] (Perchloroethylene)	25 ppm	100 ppm	A3; BEI	165.80	Irritation; CNS
Tetrachloronaphthalene [1335-88-2]	2 mg/m^3	—	—	265.96	Liver
Tetraethyl lead [78-00-2], as Pb	0.1 mg/m^3	—	Skin; A4	323.45	CNS
Tetrafluoroethylene [116-14-3]	2 ppm	—	A3	100.20	Kidney; liver
Tetrahydrofuran [109-99-9]	200 ppm	250 ppm	BEI	72.10	Irritation; narcosis
Tetramethyl lead [75-74-1], as Pb	0.15 mg/m^3	—	Skin	267.33	CNS
Tetramethyl succinonitrile [3333-52-6]	0.5 ppm	—	Skin	136.20	CNS
Tetranitromethane [509-14-8]	0.005 ppm	—	A3	196.04	Irritation
Tetrasodium pyrophosphate [7722-88-5]	5 mg/m^3	—	—	265.94	Irritation
Tetryl [479-45-8]	1.5 mg/m^3	—	—	287.15	Liver; dermatitis; sensitization
Thallium [7440-28-0] and soluble compounds, as Tl	0.1 mg/m^3	—	Skin	204.37	Irritation; CNS; CVS
4,4'-Thiobis(6-tert-butyl-m-cresol) [96-69-5]	10 mg/m^3	—	A4	358.52	Liver; kidney
Thioglycolic acid [68-11-1]	1 ppm	—	Skin	92.12	Irritation
Thionyl chloride [7719-09-7]	—	C 1 ppm	—	118.98	Irritation
Thiram [137-26-8]	1 mg/m^3	—	A4	240.44	Irritation
Tin [7440-31-5], as Sn					
Metal	2 mg/m^3	—	—	118.69	Stannosis
Oxide & inorganic compounds, except tin hydride,	2 mg/m^3	—	—	Varies	Stannosis
Organic compounds,	0.1 mg/m^3	0.2 mg/m^3	Skin; A4	Varies	CNS; immunotoxicity; irritation

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Titanium dioxide [13463-67-7]	10 mg/m^3	—	A4	79.90	Lung
o-Tolidine [119-93-7]	—	—	Skin; A3	212.28	Liver; kidney; blood
Toluene [108-88-3]	50 ppm	—	Skin; A4; BEI	92.13	CNS
‡ Toluene-2,4-diisocyanate (TDI) [584-84-9]	0.005 ppm	0.02 ppm	(—); A4	174.15	Irritation; sensitization
o-Toluidine [95-53-4]	2 ppm	—	Skin; A3; BEI	107.15	Anoxia; kidney
m-Toluidine [108-44-1]	2 ppm	—	Skin; A4; BEI	107.15	Anoxia; kidney
p-Toluidine [106-49-0]	2 ppm	—	Skin; A3; BEI	107.15	Anoxia; kidney
Tributyl phosphate [126-73-8]	0.2 ppm	—	BEI	266.32	Irritation; cholinergic
Trichloroacetic acid [76-03-9]	1 ppm	—	A3	163.39	Irritation
1,2,4-Trichlorobenzene [120-82-1]	—	C 5 ppm	—	181.46	Irritation
1,1,2-Trichloroethane [79-00-5]	10 ppm	—	Skin; A3	133.41	CNS; liver
Trichloroethylene [79-01-6]	50 ppm	100 ppm	A5; BEI	131.40	CNS; headache; liver
Trichlorofluoromethane [75-69-4]	—	C 1000	A4	137.38	CVS; CNS
Trichloronaphthalene [1321-65-9]	5 mg/m^3	—	Skin	231.51	Liver
1,2,3-Trichloropropane [96-18-4]	10 ppm	—	Skin; A3	147.43	Liver; kidney
1,1,2-Trichloro-1,2,2-trifluoroethane [76-13-1]	1000 ppm	1250 ppm	A4	187.40	Narcosis; CVS; asphyxiation
Triethanolamine [102-71-6]	5 mg/m^3	—	—	149.22	Irritation; liver; kidney
Triethylamine [121-44-8]	1 ppm	3 ppm	Skin; A4	101.19	Irritation; vision
Trifluobromomethane [75-63-8]	1000 ppm	—	—	148.92	CNS; CVS
1,3,5-Triglycidyl-s-triazinetrione [2451-62-9]	0.05 mg/m^3	—	—	297.25	Blood; reproductive; dermatitis; sensitization
Trimellitic anhydride [552-30-7]	—	C 0.04 mg/m^3	—	192.12	Bleeding (lung); immunotoxicity; sensitization
Trimethylamine [75-50-3]	5 ppm	15 ppm	—	59.11	Irritation
Trimethyl benzene (mixed isomers) [25551-13-7]	25 ppm	—	—	120.19	Irritation; CNS; blood
Trimethyl phosphite [121-45-9]	2 ppm	—	—	124.08	Irritation
2,4,6-Trinitrotoluene (TNT) [118-96-7]	0.1 mg/m^3	—	Skin; BEI	227.13	Irritation; liver; blood; eye
Triorthocresyl phosphate [78-30-8]	0.1 mg/m^3	—	Skin; A4; BEI	368.37	CNS; cholingeric
Triphenyl amine [603-34-9]	5 mg/m^3	—	—	245.33	Irritation
Triphenyl phosphate [115-86-6]	3 mg/m^3	—	A4	326.28	Irritation; dermatitis
Tungsten [7440-33-7], as W				183.85	
Metal and insoluble compounds	—	10 mg/m^3	—	Varies	Irritation
Soluble compounds	—	3 mg/m^3	—	Varies	CNS; irritation
‡ Turpentine [8006-64-2]	100 ppm	—	(—)	136.00	Irritation; (—)

Substance [CAS No.]	2001 ADOPTED VALUES			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Uranium (natural) [7440-61-1]				238.03	Kidney; blood; cancer
Soluble and insoluble compounds, as U	0.2 mg/m^3	0.6 mg/m^3	A1	Varies	
n-Valeraldehyde [110-62-3]	50 ppm	—	—	86.13	Irritation
Vanadium pentoxide [1314-62-1], dust and fume, as V_2O_5	0.05 mg/m^3 (R)	—	A4; BEI	181.90	Irritation; lung
Vegetable oil mists (M)	10 mg/m^3	—	—	—	Lung
Vinyl acetate [108-05-4]	10 ppm	15 ppm	A3	86.09	Irritation
Vinyl bromide [593-60-2]	0.5 ppm	—	A2	106.96	Liver; CNS; cancer
Vinyl chloride [75-01-4]	1 ppm	—	A1	62.50	Cancer (liver)
4-Vinyl cyclohexene [100-40-3]	0.1 ppm	—	A3	108.18	Irritation; CNS; reproductive
Vinyl cyclohexene dioxide [106-87-6]	0.1 ppm	—	Skin; A3	140.18	Irritation; dermatitis; reproductive
Vinyl fluoride [75-02-5]	1 ppm	—	A2	46.05	Liver; cancer
Vinylidene chloride [75-35-4]	5 ppm	—	A4	96.95	CNS; liver; kidney
Vinylidene fluoride [75-38-7]	500 ppm	—	A4	64.04	Liver
Vinyl toluene [25013-15-4]	50 ppm	100 ppm	A4	118.18	Irritation
VM & P Naphtha [8032-32-4]	300 ppm	—	A3	114.00	Irritation; CNS
Warfarin [81-81-2]	0.1 mg/m^3	—	—	308.32	Blood; bleeding
Welding fumes (NOS)	5 mg/m^3	—	B2	—	Lung; metal fume fever; irritation
‡ Wood dust					
‡ (Certain hard woods as beech & oak)	(1 mg/m^3)	—	(—); A1	—	Cancer; irritation; mucostasis; dermatitis
‡ (Soft wood)	5 mg/m^3	(10 mg/m^3)	(—)	—	Irritation; dermatitis; lung
Xylene [1330-20-7] (o, m & p isomers) [95-47-6; 108-38-3; 106-42-3]	100 ppm	150 ppm	A4; BEI	106.16	Irritation
m-Xylene α,α'-diamine [1477-55-0]	—	C 0.1 mg/m^3	Skin	136.20	Irritation; blood
‡ Xylidine (mixed isomers) [1300-73-8]	(0.5 ppm)	—	Skin; A3; BEI	121.18	Cancer; genotoxic
Yttrium [7440-65-5] and compounds, as Y	1 mg/m^3	—	—	88.91	Fibrosis
Zinc chloride fume [7646-85-7]	1 mg/m^3	2 mg/m^3	—	136.29	Irritation; lung dema
Zinc chromates [13530-65-9; 11103-86-9; 37300-23-5], as Cr	0.01 mg/m^3	—	A1	Varies	Cancer (lung)
Zinc oxide [1314-13-2]				81.37	
Fume	5 mg/m^3	10 mg/m^3	—		Lung; metal fume fever
Dust	10 mg/m^3	—	—		Lung
Zirconium [7440-67-7] and compounds, as Zr	5 mg/m^3	10 mg/m^3	A4	91.22	Lung

NOTICE OF INTENDED CHANGES (for 2001)

These substances, with their corresponding values, comprise those for which either a limit has been proposed for the first time or for which a change in the Adopted TLV has been proposed. In each case, the proposed values should be considered trial values for the year following ratification by the ACGIH Board of Directors. If, during the year, no evidence comes to light that questions the appropriateness of these proposals, the values will be reconsidered for the adoption as TLVs. Documentation is available for each of these substances and their proposed values.

This notice provides not only the opportunity for comment on these proposals but also solicits suggestions of substances to be considered for TLVs, like those on the current list of "Chemical Substances and Other Issues Under Study." Comments or suggestions should be accompanied by substantiating evidence, preferably in electronic format, and forwarded to the The Science Group, ACGIH.

Substance [CAS No.]	Notice of Intended Changes (for 2001)			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
† Acetonitrile [75-05-8]	20 ppm	—	Skin; A4	41.05	Lung
† tert-Amyl methyl ether (TAME) [994-05-8]	20 ppm	—	—	102.20	Neurologic; reproductive
† Arsine [7784-42-1]	0.003 ppm	—	A1	77.95	Blood; cancer
† Azinphos-methyl [86-50-0]	0.2 mg/m^3 (I, V)	—	Skin; SEN; A4; BEI	317.34	Cholinergic
Beryllium [7440-41-7] and compounds, as Be	0.0002 mg/m^3 (I)	—	SEN; A1	9.01	Cancer (lung); berylliosis; sensitization
† n-Butanol [71-36-3]	20 ppm	—	—	74.12	Irritation
† Butoxyethanol (EGBE) [111-76-2]	2o ppm	—	—	118.17	Irritation; CNS
Caprolactam [105-60-2], aerosol and vapor	5 mg/m^3 (V)	—	A5	113.16	Irritation
† Captan [133-06-2]	5 mg/m^3 (I)	—	SEN; A3	300.60	Irritation
† 1-Chloro-2-propanol [127-00-4] and 2-Chloro-1-propanol [78-89-7]	1 ppm	—	Skin; A4	94.54	Reproductive
† Chlorpyrifos [2921-88-2]	0.1 mg/m^3 (I)	—	Skin; A4; BEI	350-57	Cholinergic
† Cyclohexane [110-82-7]	100 ppm	—	—	84.16	CNS
Demeton [8065-48-3]	0.05 mg/m^3 (I, V)	—	Skin; BEI	258.34	Cholinergic
Demeton-S-methyl [919-86-8]	0.05 mg/m^3 (I, V)	—	Skin; SEN; A4; BEI	230.3	Cholinergic
† Diazinon [333-41-5]	0.1 mg/m^3 (I, V)	—	Skin; A4; BEI	304-36	Cholinergic
† Dichlorvos [62-73-7]	0.1 mg/m^3 (I, V)	—	Skin; SEN; A4; BEI	220.98	Cholinergic
Dicrotophos [141-66-2]	0.05 mg/m^3 (I, V)	—	Skin; A4; BEI	237.21	Cholinergic

Substance [CAS No.]	Notice of Intended Changes (for 2001)			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Diesel exhaust, as elemental carbon	0.02 mg/m^3	—	A2	—	Cancer; lung
Diesel fuel	100 mg/m^3	—	Skin; A3	Varies	Skin; irritation
Dioxathion [78-34-2]	0.1 mg/m^3 (I, V)	—	Skin; A4; BEI	456.54	Cholinergic
† Disulfoton [298-04-4]	0.05 mg/m^3 (I, V)	—	Skin; A4; BEI	274.38	Cholinergic
1,3-Dioxolane [646-06-0]	20 ppm	—	—	74.08	Irritation; liver
Ethion [563-12-2]	0.05 mg/m^3 (I, V)	—	Skin; A4; BEI	384.48	Cholinergic
Ethyl benzene [100-41-4]	100 ppm	125 ppm	A3; BEI	106.16	Irritation; CNS
† Ethylhexanoic acid [149-57-5]	5 mg/m^3 (I, V)	—	—	144.24	Reproductive
† 1-Hexene [592-41-6]	50 ppm	—	—	84.16	CNS; reproductive
Hydrogen sulfide [7783-06-4]	5 ppm	—	—	34.08	Sudden death; irritation; CNS
Isopropanol (Isopropyl alcohol) [67-63-0]	200 ppm	400 ppm	A4	60.09	Irritation
Isopropyl acetate {108-21-4]	100 ppm	200 ppm	—	102.13	Irritation
† Methyl tert-butyl ether (MTBE) [1634-04-4]	50 ppm	—	A3	88.17	Reproductive; kidney
Mevinphos [7786-34-7]	0.01 mg/m^3 (I, V)	—	Skin; SEN; A4; BEI	224.16	Cholinergic
Molybdenum [7439-98-7], as Mo					
† Soluble compounds	0.5 mg/m^3 (R)	—	A2	Varies	Irritation; cancer; lung
† Monocrotophos [6923-22-4]	0.05 mg/m^3 (I, V)	—	Skin; A4; BEI	223.16	Cholinergic
Naled [300-76-5]	0.1 mg/m^3 (I, V)	—	Skin; SEN; A4; BEI	380.79	Cholinergic
† Oil mist, mineral	0.2 mg/m^3 (I)	—	A2	NA	Respiratory
† Parathion [56-38-2]	0.05mg/m^3 (I, V)	—	Skin; A4; BEI	291.27	Cholinergic
n-Propanol [71-23-8]	200 ppm	250 ppm	A3	60.09	Irritation; liver; kidney
† Propionaldehyde [123-38-6]	20 ppm	—	—	58.10	Irritation; nasal
† Propylene [115-07-1]	200 ppm	—	A4	42.08	Irritation; kdney; nasal
† Silicon carbide [409-21-2]				40.10	
Nonfibrous	10 mg/m^3 (I, E)	—	—		Lung function
	3 mg/m^3 (R, E)	—	—		Lung function
Fibrous forms (including whiskers)	0.1 f/cc	—	—		Lung fibrosis; cancer
Sodium sesquicarbonate (Trona) [533-96-0]	0.5 mg/m^3 (R)	—	—	226.03	Irritation; pulmonary function
† Sulfuric acid [7664-93-9]	0.1 mg/m^3 (I)	—	A2(M)	98.308	Mucostasis; lung function
Terbufos [13071-79-9]	0.01 mg/m^3 (I, V)	—	A4; BEI	288.45	Cholinergic
Toluene-2,4- or 2,6-diisocyanate [584-84-9; 91-08-7]	0.005 ppm	0.02 ppm	SEN; A4	174.15	Respiratory; sensitization

Substance [CAS No.]	Notice of Intended Changes (for 2001)			Mol Wgt	TLV Basis — Critical Effect(s)
	TWA	STEL	Notations		
Trichlorphon [52-68-6]	1 mg/m^3 (I, V)	—	SEN	257.60	Cholinergic
Turpentine [8006-64-2]	100 ppm	—	SEN	136.00	Irritation; sensitization
Wood dust					
† Nonallergenic and non carcinogenic)	2 mg/m^3 (I)	—	A4	—	Respiratory; lung function
Western red cedar	0.5 mg/m^3 (I)	—	SEN; A4	—	Asthma; respiratory; lung function
† Other respiratory allergenic wood dust	1 mg/m^3 (I)	—	SEN; A4	—	Asthma; respiratory; lung function
† Birch, Mahogany, Teak, Walnut	1 mg/m^3 (I)	—	A2	—	Cancer (nasal); respiratory; lung function
† Oak and Beech	1 mg/m^3 (I)	—	A1	—	Cancer (nasal); respiratory; lung function
† Xylidine (mixed isomers) [1330-73-8]	0.5 ppm (I,V)	—	Skin; A3; BEI	223.16	Cancer

ADOPTED APPENDICES

APPENDIX A: CARCINOGENICITY

ACGIH has been aware of the increasing public concern over chemicals or industrial processes that cause or contribute to increased risk of cancer in workers. More sophisticated methods of bioassay, as well as the use of sophisticated mathematical models that extrapolate the levels of risk among workers, have led to differing interpretations as to which chemicals or processes should be categorized as human carcinogens and what the maximum exposure levels should be. The goal of the Chemical Substances TLV Committee has been to synthesize the available information in a manner that will be useful to practicing industrial hygienists, without overburdening them with needless details. The categories for carcinogenicity are:

A1 — Confirmed Human Carcinogen: The agent is carcinogenic to humans based on the weight of evidence from epidemiologic studies.

A2 — Suspected Human Carcinogen: Human data are accepted as adequate in quality but are conflicting or insufficient to classify the agent as a confirmed human carcinogen; OR, the agent is carcinogenic in experimental animals at dose(s), by route(s) of exposure, at site(s), of histologic types(s), or by mechanism(s) considered relevant to worker exposure. The A2 is used pri-marily when there is limited evidence of carcino-genicity in humans and sufficient evidence of carcinogenicity in experimental animals with relevance to humans.

A3 — Confirmed Animal Carcinogen with Unknown Relevance to Humans: The agent is carcinogenic in experimental animals at a relatively high dose, by route(s) of administra-tion, at site(s), of histologic types(s), or by mech-anism(s) that may not be relevant to worker expo-sure. Available epidemiologic studies do not con-firm an increased risk of cancer in exposed humans. Available evidence does not suggest that the agent is likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.

A4 — Not Classifiable as a Human Carcinogen: Agents which cause concern that they could be carcinogenic for humans but which cannot be assessed conclusively because of a lack of data. *In vitro* or animal studies do not provide indications of carcinogenicity which are sufficient to classify the agent into one of the other categories.

A5 — Not Suspected as a Human Carcinogen: The agent is not suspected to be a human carcinogen on the basis of properly conducted epidemiologic studies in humans. These studies have sufficiently long follow-up, reliable exposure histories, sufficiently high dose, and adequate statistical power to conclude that exposure to the agent does not convey a significant risk of cancer to humans; OR, the evidence suggesting a lack of carcinogenicity in experimental animals is supported by mechanistic data.

Substances for which no human or experimental animal carcinogenic data have been reported are assigned no carcinogenicity designation.

Exposures to carcinogens must be kept to a minimum. Workers exposed to A1 carcinogens without a TLV should be properly equipped to eliminate to the fullest extent possible all exposure to the carcinogen. For A1 carcinogens with a TLV and for A2 and A3 carcinogens, worker exposure by all routes should be carefully controlled to levels as low as possible below the TLV. Refer to the "Guidelines for the Classification of Occupational Carcinogens" in the Introduction to the *Documentation of the Threshold Limit Values and Biological Exposure Indices* for a more complete description and derivation of these designations.

APPENDIX B: Substances of Variable Composition

B1. *Polytetrafluoroethylene* decomposition products.* Thermal decomposition of the fluorocarbon chain in air leads to the formation of oxidized products containing carbon, fluorine, and oxygen. Because these products decompose in part by hydrolysis in alkaline solution, they can be quantitatively determined in air as fluoride to provide an index of exposure. No TLVs are recommended at this time, but air concentration should be controlled as low as possible.

*Some trade names include: Algoflon®, Fluon®, Teflon®, Tetran®.

B2. *Welding Fumes—Total Particulate (not otherwise specified)*: *TLV–TWA*, 5 mg/m³
Welding fumes cannot be classified simply. The composition and quantity of both are dependent on the alloy being welded and the process and electrodes used. Reliable analysis of fumes cannot be made without considering the nature of the welding process and system being examined; reactive metals and alloys such as aluminum and titanium are arc-welded in a protective, inert atmosphere such as argon. These arcs create relatively little fume, but they do create an intense radiation which can produce ozone. Similar processes are used to arc-weld steels, also creating a relatively low level of fumes. Ferrous alloys also are arc-welded in oxidizing environments that generate considerable fume and can produce carbon monoxide instead of ozone. Such fumes generally are composed of discrete particles of amorphous slags containing iron, manganese, silicon, and other metallic constituents depending on the alloy system involved. Chromium and nickel compounds are found in fumes when stainless steels are arc- welded. Some coated and flux-cored electrodes are formulated with fluorides and the fumes associated with them can contain significantly more fluorides than oxides. Because of the above factors, arc-welding fumes frequently must be tested for individual constituents that are likely to be present to determine whether specific TLVs are exceeded. Conclusions based on total concentration are generally adequate if no toxic elements are present in welding rod, metal, or metal coating and conditions are not conducive to the formation of toxic gases.

APPENDIX C: Threshold Limit Values for Mixtures

When two or more hazardous substances which act upon the same organ system are present, their combined effect, rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, the effects of the different hazards should be considered as additive. That is, if the sum of

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \Lambda\ \frac{C_n}{T_n}$$

exceeds unity, then the threshold limit of the mixture should be considered as being exceeded. C_1 indicates the observed atmospheric concentration and T_1 the corresponding threshold limit (see Example A.1 and B.1).

Exceptions to the above rule may be made when there is a good reason to believe that the chief effects of the different harmful substances are not in fact additive, but are independent as when purely local effects on different organs of the body are produced by the various components of the mixture. In such cases, the threshold limit ordinarily is exceeded only when at least one member of the series (C_1/T_1 + or + C_2/T_2, etc.) itself has a value exceeding unity (see Example B.1).

Synergistic action or potentiation may occur with some combinations of atmospheric contaminants. Such cases at present must be determined individually. Potentiating or synergistic agents are not necessarily harmful by themselves. Potentiating effects of exposure to such agents by routes other than that of inhalation are also possible, e.g., imbibed alcohol and inhaled narcotic (trichloroethylene). Potentiation is characteristically exhibited at high concentrations, less probably at low.

When a given operation or process characteristically emits a number of harmful dusts, fumes, vapors or gases, it will frequently be only feasible to attempt to evaluate the hazard by measurement of a single substance. In such cases, the threshold limit used for this substance should be reduced by a suitable factor, the magnitude of which will depend on the number, toxicity, and relative quantity of the other contaminants ordinarily present.

Examples of processes that are typically associated with two or more harmful atmospheric contaminants are welding, automobile repair, blasting, painting, lacquering, certain foundry operations, diesel exhausts, etc.

Examples of TLVs for Mixtures

A. *Additive effects.* The following formulae apply only when the components in a mixture have similar toxicologic effects; they should not be used for mixtures with widely differing reactivities, e.g., hydrogen cyanide and sulfur dioxide. In such case, the formula for **Independent Effects** should be used.

1. General case, where air is analyzed for each component, the TLV of mixture =

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \Lambda\ = 1$$

Note: It is essential that the atmosphere be analyzed both qualitatively and quantitatively for each component present in order to evaluate compliance or noncompliance with this calculated TLV.

Example A.1: Air contains 400 ppm of acetone (TLV, 500 ppm), 150 ppm of sec-butyl acetate (TLV, 200 ppm) and 100 ppm of methyl ethyl ketone (TLV, 200 ppm).

Atmospheric concentration of mixture = 400 + 150 + 100 = 650 ppm of mixture.

$$\frac{400}{500}+\frac{150}{200}+\frac{100}{200}=0.80+0.75+0.5=2.05$$

.....Threshold Limit is exceeded.

2. Special case when the source of contaminant is a liquid mixture and the atmospheric composition is assumed to be similar to that of the original material, e.g., on a time-weighted average exposure basis, all of the liquid (solvent) mixture eventually evaporates. When the percent composition (by weight) of the liquid mixture is known, the TLVs of the constituents must be listed in mg/m^3. TLV of mixture =

$$\frac{1}{\frac{f_a}{TLV_a}+\frac{f_b}{TLV_b}+\frac{f_c}{TLV_c}+\Lambda\ \frac{f_n}{TLV_n}}$$

Note: In order to evaluate compliance with this TLV, field sampling instruments should be calibrated, in the laboratory, for response to this specific quantitative and qualitative air–vapor mixture, and also to fractional concentrations of this mixture, e.g., 1/2 the TLV; 1/10 the TLV; 2 x the TLV; 10 x the TLV; etc.)

Example A.2: Liquid contains (by weight):

50% heptane: TLV = 400 ppm or 1640 mg/m^3
1 mg/m^3 ≡ 0.24 ppm

30% methyl chloroform: TLV 350 ppm or 1910 mg/m^3
1 mg/m^3 ≡ 0.18 ppm

20% perchloroethylene: TLV = 25 ppm or 170 mg/m^3
1 mg/m^3 ≡ 0.15 ppm

$$\text{TLV of Mixture} = \frac{1}{\frac{0.5}{1640}+\frac{0.3}{1910}+\frac{0.2}{170}}$$

$$= \frac{1}{0.00030+0.00016+0.00118}$$

$$= \frac{1}{0.00164}$$

$$= 610\ \text{mg/m}^3$$

of this mixture

50% or (610)(0.5) = 305 mg/m^3 is heptane
30% or (610)(0.3) = 183 mg/m^3 is methyl chloroform
20% or (610)(0.2) = 122 mg/m^3 is perchloroethylene

These values can be converted to ppm as follows:

heptane: 305 mg/m^3 x 0.24 = 73 ppm
methyl chloroform: 183 mg/m^3 x 0.18 = 33 ppm
perchloroethylene: 122 mg/m^3 x 0.15 = 18 ppm

TLV of mixture = 73 + 33 + 18 = 124 ppm, or 610 mg/m^3

B. ***Independent effects.*** TLV for mixture =

$$\frac{C_1}{T_1}=1;\quad \frac{C_2}{T_2}=1;\quad \frac{C_3}{T_3}=1;\quad \text{etc.}$$

Example B.1: Air contains 0.05 mg/m^3 of lead (TLV, 0.05) and 0.7 mg/m^3 of sulfuric acid (TLV, 1).

$$\frac{0.05}{0.05}=1;\quad \frac{0.7}{1}=0.7$$

Threshold limit is not exceeded.

C. ***TLV for mixtures of mineral dusts.*** For mixtures of biologically active mineral dusts, the general formula for mixtures given in A.2 may be used.

APPENDIX D: Particle Size-Selective Sampling Criteria for Airborne Particulate Matter

For chemical substances present in inhaled air as suspensions of solid particles or droplets, the potential hazard depends on particle size as well as mass concentration because of: 1) effects of particle size on the deposition site within the respiratory tract, and 2) the tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract.

ACGIH has recommended particle size-selective TLVs for crystalline silica for many years in recognition of the well-established association between silicosis and respirable mass concentrations. The Chemical Substances TLV Committee is now re-examining other chemical substances encountered in particulate form in occupational environments with the objective of defining: 1) the size-fraction most closely associated for each

substance with the health effect of concern, and 2) the mass concentration within that size fraction which should represent the TLV.

The Particle Size-Selective TLVs (PSS–TLVs) are expressed in three forms:

1. *Inhalable Particulate Mass TLVs* (IPM–TLVs) for those materials that are hazardous when deposited anywhere in the respiratory tract.
2. *Thoracic Particulate Mass TLVs* (TPM–TLVs) for those materials that are hazardous when deposited anywhere within the lung airways and the gas-exchange region.
3. *Respirable Particulate Mass TLVs* (RPM–TLVs) for those materials that are hazardous when deposited in the gas-exchange region.

The three particulate mass fractions described above defined in quantitative terms in accordance with the following equations:[1–2]

A. IPM consists of those particles that are captured according to the following collection efficiency regardless of sampler orientation with respect to wind direction:

$$IPM(d_{ae}) = 0.5[1 + \exp(-0.06\, d_{ae})]$$

$$\text{for } 0 < d_{ae} \leq 100\ \mu m$$

where:

$IPM(d_{ae})$ = the collection efficiency

d_{ae} = aerodynamic diameter of particle in μm

B. TPM consists of those particles that are captured according to the following collection efficiency:

$$TPM(d_{ae}) = IPM(d_{ae})\,[1 - F(x)]$$

where:

F(x) = cumulative probability function of the standardized normal variable, x

$$x = \frac{\ln(d_{ae} / \Gamma)}{\ln(\Sigma)}$$

ln = natural logarithm

$\Gamma = 11.64$

$\Sigma = 1.5$

C. RPM consists of those particles that are captured according to the following collection efficiency:

$$RPM(d_{ae}) = IPM(d_{ae})\,[1 - F(x)]$$

where:

F(x) = same as above, but with $\Gamma = 4.25$ μm and $\Sigma = 1.5$.

The most significant difference from previous definitions is the increase in the median cut point for a respirable particulate matter sampler from 3.5 μm to 4.0 μm; this is in accord with the Interational Organization for Standardization/ European Standardization Committee (ISO/CEN) protocol.[4,5] At this time, no change is recommended for the measurement of respirable particulates using a 10-mm nylon cyclone at a flow rate of 1.7 liters per minute. Two analyses of available data indicate that the flow rate of 1.7 liters per minute allows the 10- mm nylon cyclone to approximate the particulate matter concentration which would be measured by an ideal respirable particulate sampler as defined herein.[6,7]

Collection efficiencies representative of several sizes of particles in each of the respective mass fractions are shown in Tables 1, 2, and 3. Documentation for the respective algorithms representative of the three mass fractions, is found in the literature.[2–4].

TABLE 1. Inhalable

Particle Aerodynamic Diameter (μm)	Inhalable Particulate Mass (IPM) (%)
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5
50	52.5
100	50

TABLE 2. Thoracic

Particle Aerodynamic Diameter (μm)	Thoracic Particulate Mass (TPM) (%)
0	100
2	94
4	89
6	80.5
8	67
10	50
12	35
14	23
16	15
18	9.5
20	6
25	2

TABLE 3. Respirable

Particle Aerodynamic Diameter (μm)	Respirable Particulate Mass (RPM) (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

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4. International Organization for Standardization (ISO): Air Quality — Particle Size Fraction Definitions for Health-Related Sampling. Approved for publication as CD 7708. ISO, Geneva (1991).
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6. Bartley, D.L.: Letter to J. Doull, TLV Committee, July 9, 1991.
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CHEMICAL SUBSTANCES AND OTHER ISSUES UNDER STUDY

The Chemical Substances TLV Committee solicits information, especially data, which may assist the Committee in its deliberations regarding the following substances and issues. Comments and suggestions, accompanied by substantive supporting data, should be forwarded to The Science Group, ACGIH. In addition, the Committee solicits recommendations for additional substances and issues of concern to the Industrial Hygiene and Occupational Health communities.

Chemical Substances

Acetic acid
Acetophenone
Acetylene tetrabromide
Acrylamide
Alachlor
Aldrin
Allyl alcohol
Allyl propyl disulfide
Aluminum and compounds
1-Amino-3-dimethylaminopropane
alha-Amylase
Antimony and compounds
Arsenic pentoxide
Asbestos — Chrysotile
Asphalt fumes
Aviation gasoline
Benzaldehyde
Benzofuran
Bisphenol A
Boron and borates
Bromochloromethane
Bromodichloromethane
Bromoform
Butane
1,2,3,4-Butanetetracarboxylic acid
sec-Butanol
Butyl acetate, all isomers
tert-Butylamine
1,2-Butylene oxide
n-Butyl glycidyl ether [BGE]
tert-Butyl hydroquinone
n-Butyl lactate
2-t-Butylazo-2-hydroxy-5-methylhexane
2-Butylhexanoic acid
tert-Butylhydroquinone [TBHQ]
2-Butoxyethyl acetate [EGBEA]
Butyl mercaptan
Calcium cyanamide
Captafol
Carbaryl
Carbofuran
Carbon black
Carbon disulfide
Chlkoroacetic acid
Chlorodiphenyls [42% and 54% chlorine]
Cobalt and inorganic compounds

Cobalt carbonyl
Copper
Cotton dust
Coumaphos
Creosote
Cresol
Cyanamide
Cyclohexanone
Diaminotoluene
Dichloroacetic acid
Dichlorodiphenyl sulfone
1,2-Dichloroethane
1,3-Dichloropropene
Dichlorvos
Dicyclopentadiene
Diethanolamine
1,4-Diethyl benzene
Diethylene glycol
Diethylhydroxyamine [DEHA]
Diglycidyl ether [DGE]
1,2-Dihydro-2,2,4-trimethylquinoline
Dimethyl disulfide
Dimethylene glycol monobutyl ether
Dimethyl sulfide
Dimethyl sulfoxide
Dimethylterephthalate
Dinitrotoluene
Divinyl benzene
Dodectyl mercaptan
Endosulfan
EPN
Ethanol [Ethyl alcohol]
2-Ethoxyethanol [EGEE]
2-Ethoxyethyl acetate [EGEEA]
Ethyl acetate
Ethyl acrylate
Ethyl amyl ketone [5-Methyl-3-heptanone]
Ethyl bromide
Ethyl carbamate
Ethyl ether [Diethyl ether]
Ethyl mercaptan
Ethylene
Fenamiphos
Fensulfothion
Fenthion
Ferbam
Flour dust
Fonofos
Furan
Furfural alcohol
Gallium arsenide
Gasoline, unleaded
Glutaraldehyde
n-Heptane
Hexachlorocyclopentadiene
Hexafluoropropylene
Hexahydrophthalic anhydride
Hydrogen bromide
Hydrogen chloride
Hydrogen fluoride
Hydrogen iodide
Hydroquinone
Iron oxide
Isobutane
Isobutene
Isobutyl nitrate
2-Isopropoxyethanol
Isopropyl ether
Isopropyl glycidyl ether [IGE]
Jet fuel
Kerosene
LPG (Liquified petroleum gas)
Magnesium
Malathion
Maleic anhydride
Manganese and inorganic compound
Melamine
Metal carbonyls
Methane
Methomyl
2-Methoxyethanol [EGME]
2-Methoxyethyl acetate [EGMEA]
1-Methoxy-2-propanol
Methyl acrylate
Methylacrylonitrile
Methyl n-amyl ketone [2-Heptanone]
Methyl demeton
Methylenediamine
4,4'-Methylene dianiline
Methyl ethyl ketone [2-Butanone]
Methyl isoamyl ketone
Methyl isobutyl ketone
Methyl mercaptan
1-Methyl naphthalene
2-Methyl naphthalene
Methyl parathion
Methyl propyl ketone [2-Pentanone]
Methylene diamine
4,4'-Methylene dianiline
Methyl mercaptan
1-Methyl naphthalene
2-Methyl naphthalene
Methyl propyl ketone [2-Pentanone]
alpha-Methyl styrene
Mineral spirits
Naphthalene
2-Naphthylamine
Natural rubber latex
Nickel carbonyl
5-Nitro-ortho-toluidine
Octane (all isomers)
Ozone

Particulates (Insoluble) Not Otherwise Specified (PNOS)
Pentachlorophenol
2,4-Pentanedione
Persulfates
Petroleum solvents
Phenol
Phenyl mercaptan
ortho-Phenyl phenol
Phosphorus pentachloride
Phosphorus pentoxide
Phorate
Phosgene
Phthalic anhydride
Polymeric MDI
Polyvinyl chloride (PVC) dust
Portland cement
Pot ash
Propylene dichloride
Propylene glycol
Propylene glycol monomethyl ether
2-Propylhexanoic acid
Phthalic anhydride
Pyridine
Quinone
Ronnel
Rouge
Silica, crystalline — Cristobalite
Silica, crystalline — Tridymite
Silica, crystalline — Tripoli
Subtilisins [Enzymes]
Sulfotep [TEDP]
Sulfur dioxide
Sulprofos
Temephos
TEPP
Tetrahydrofuran
Tetrakis (hydroxymethyl) phosphonium chloride
Tetrakis (hydroxymethyl) phosphonium sulfate
Tin, metal
Toluene [Toluol]
Trichloroacetic acid
Trihydroxyethyl hexahydrotriazine
Trimelletic anhydride
Tungsten carbide
Uranium
Vanadium pentoxide, respirable dust or fume
Vinyl acetatae
N-Vinyl-2-pyrrolidone
Welding fumes
Xylene (o, m, & p-isomers) [Dimethyl benzene]
Zinc oxide

Other Issues

1. Ceiling Limit, excursion limit, and short-term exposure limit.
2. Notations for reproductive effects.
3. Risk assessment.
4. Neurotoxicity.
5. Variable work schedules.
6. Skin notation.
7. Soluble and insoluble compounds (other than metals).
8. Complex mixtures.
9. Lung particulate overload.
10. Reciprocal method for hydrocarbon mixtures.

2000 CHEMICAL SUBSTANCES TLV COMMITTEE

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2001

Biological Exposure Indices

Adopted by ACGIH©
with Intended Changes

Contents

INTRODUCTION TO THE BIOLOGICAL EXPOSURE INDICES

Biological monitoring provides one of the means to assess the exposure and health risk to workers. It entails the measurement of the concentration of a chemical determinant in the biological media of those exposed and is an indicator of the uptake of a substance. Biological Exposure Indices (BEIs) are guidance values for assessing biological monitoring results. BEIs represent the levels of determinants which are most likely to be observed in specimens collected from healthy workers who have been exposed to chemicals to the same extent as workers with inhalation exposure at the Threshold Limit Value (TLV). The exceptions are the BEIs for chemicals for which the TLVs are based on protection against nonsystemic effects (e.g., irritation or respiratory impairment) where biological monitoring is desirable because of the potential for significant absorption via an additional route of entry (usually the skin). Biological monitoring indirectly reflects the dose to a worker from exposure to the chemical of interest. The BEI generally indicates a concentration below which nearly all workers should not experience adverse health effects. The BEI determinant can be the chemical itself; one or more metabolite; or a characteristic, reversible biochemical change induced by the chemical. In most cases, the specimen used for biological monitoring is urine, blood, or exhaled air. The BEIs are not intended for use as a measure of adverse effects or for diagnosis of occupational illness.

Biological monitoring can assist the occupational health professional detect and determine the absorption via the skin or gastrointestinal system, in addition to that by inhalation; assess body burden; reconstruct past exposure in the absence of other exposure measurements; detect nonoccupational exposure among workers; test the efficacy of personal protective equipment and engineering controls; and monitor work practices.

Biological monitoring serves as a complement to exposure assessment by air sampling. The existence of a BEI does not indicate a need to conduct biological monitoring. Conducting, designing, and interpreting biological monitoring protocols and the application of the BEI requires professional experience in occupational health and reference to the current edition of the *Documentation of the Threshold Limit Values and Biological Exposure Indicies* (ACGIH).

DOCUMENTATION

BEIs are developed by Committee consensus through an analysis and evaluation process. The detailed scientific criteria and justification for each BEI can be found in the Documentation of the Threshold Limit Values and Biological Exposure Indices. The principal material evaluated by the BEI Committee includes peer-reviewed, published data taken from the workplace (i.e., field studies), data from controlled exposure studies, and from appropriate pharmacokinetic modeling when available. The results of animal research are also considered when relevant. The Documentation provides essential background information and the scientific reasoning used in establishing each BEI. Other information given includes the analytical methods, possible potential for confounding exposures, specimen collection recommendations, limitations, and other pertinent information.

In recommending a BEI, the Committee considers whether published data are of reasonable quality and quantity and may also consider unpublished data if verified. There are numerous instances when analytical techniques are available for the measurement of a biological determinant, but published information is unavailable or unsuitable for determining a BEI. In those instances, occupational health professionals are encouraged to accumulate and report biological monitoring data together with exposure and health data.

Relationship of BEIs to TLVs

BEI determinants are an index of an individual's "uptake" of a chemical(s). Air monitoring to determine the TLV indicates the potential inhalation "exposure" of an individual or group. The uptake within a workgroup may be different for each individual for a variety of reasons, some of which are indicated below. Most BEIs are based on a direct correlation with the TLV (i.e., the concentration of the determinant which can be expected when the airborne concentration is at the TLV). Some of the BEIs (e.g., lead) are not derived from the TLV but directly relate to the development of

an adverse health effect. The basis of each BEI is provided in the Documentation.

Inconsistencies may be observed between the information obtained from air monitoring and biological monitoring for a variety of reasons, including, but not limited to, work-related and methodological factors. Examples are listed below:

- Physiological makeup and health status of the worker, such as body build, diet (water and fat intake), metabolism, body fluid composition, age, gender, pregnancy, medication, and disease state.
- Occupational exposure factors, such as the work-rate intensity and duration, skin expo-sure, temperature and humidity, co-exposure to other chemicals, and other work habits.
- Nonoccupational exposure factors, such as community and home air pollutants, water and food components, personal hygiene, smoking, alcohol and drug intake, exposure to house-hold products, or exposure to chemicals from hobbies or from another workplace.
- Methodological factors, such as specimen contamination or deterioration during collection and storage and bias of the selected analytical method.
- Location of the air monitoring device in relation to the worker's breathing zone.
- Particle size distribution and bioavailability.
- Variable effectiveness of personal protective devices.

Specimen Collection

Because the concentration of some determi-nants can change rapidly, the specimen collection time (sampling time) is very important and must be observed and recorded carefully. The sampling time is specified in the BEI and is determined by the duration of retention of the determinant. Substances and determinants which accumulate may not require a specific sampling time. An explanation of the BEI sampling time is as follows:

Sampling Time.....	Recommended Collection
1. Prior to shift.....	16 hours after exposure ceases
2. During shift	Anytime after 2 hours of exposure
3. End of shift	As soon as possible after exposure ceases
4. End of the workweek	After four or five consecutive working days with exposure
5. Discretionary	At any time

Urine Specimen Acceptability

Urine specimens that are highly dilute or highly concentrated are generally not suitable for monitor-ing. The World Health Organization has adopted guidelines for acceptable limits on urine specimens as follows:

Creatinine concentration: >0.3 g/L and <3.0 g/L
or
Specific gravity: >1.010 and <1.030

Specimens falling outside either of these ranges should be discarded, and another specimen should be collected. Workers who provide consis-tently unacceptable urine specimens should be referred for medical evaluation.

Some BEIs for determinants whose concentra-tion is dependent on urine output are expressed relative to creatinine concentration. For other determinants such as those excreted by diffusion, correction for urine output is not appropriate. In general, the best correction method is chemical-specific, but research data sufficient to identify the best method may not be available. When the field data are only available as adjusted for creatinine, the BEI will continue to be expressed relative to creatinine; in other circumstances, no correction is recommended, and the BEI will be expressed as concentration in urine.

Quality Assurance

Each aspect of biological monitoring should be conducted within an effective quality assurance (QA) program. The appropriate specimen must be collected, at the proper time, without contamination or loss, and with use of a suitable container. Donor identification, time of exposure, source of Exposure, and the sampling time must be recorded. The analytical method used by the laboratory must have the accuracy, sensitivity, and specificity needed to produce results consistent with the BEI. Appropriate quality-control specimens should be included in the analysis, and the laboratory must follow routine quality control rules. The laboratory should participate in an external proficiency program.

The occupational health professional should provide known blind challenges to the laboratory along with worker specimens (e.g., blanks, purchased or spiked specimens containing the determinant, or split specimens). These blind challenges will enable the occupational health professional to assess the ability of the laboratory to process, analyze, and report results properly and to have confidence in the laboratory's ability to measure the worker's BEI accurately. When blind challenges are used, the spiked determinant

should be in the same chemical form and matrix as that being analyzed by the laboratory.**Notations**

"B" = background

The determinant may be present in biological specimens collected from subjects who have not been occupationally exposed, at a concentration which could affect interpretation of the result. Such background concentrations are incorporated in the BEI value.

"Nq" = nonquantitative

Biological monitoring should be considered for this compound based on the review; however, a specific BEI could not be determined due to insufficient data.

"Ns" = nonspecific

The determinant is nonspecific, since it is also observed after exposure to other chemicals.

"Sq" = semi-quantitative

The biological determinant is an indicator of exposure to the chemical, but the quantitative interpretation of the measurement is ambiguous. These determinants should be used as a screening test if a quantitative test is not practical or as a confirmatory test if the quantitative test is not specific and the origin of the determinant is in question.

Note:

It is essential to consult the specific BEI *Documentation* before designing biological monitoring protocols and interpreting BEIs.

Application of BEIs

BEIs are intended as guidelines to be used in the evaluation of potential health hazards in the practice of occupational hygiene. BEIs do not indicate a sharp distinction between hazardous and nonhazardous exposures. For example, it is possible for an individual's determinant concentration to exceed the BEI without incurring an increased health risk. If measurements in specimens obtained from a worker on different occasions persistently exceed the BEI, the cause of the excessive value should be investigated and action taken to reduce the exposure. An investigation is also warranted if the majority of the measurements in specimens obtained from a group of workers at the same workplace and workshift exceed the BEI. It is desirable that relevant information on related operations in the workplace be recorded.

Due to the variable nature of concentrations in biological specimens, dependence should not be placed on the results of one single specimen. Administrative action should not be normally based on a single isolated measurement, but on measurements of multiple sampling, or an analysis of a repeat specimen. It may be appropriate to remove the worker from exposure following a single high result if there is reason to believe that significant exposure may have occurred. Conversely, observations below the BEI do not necessarily indicate a lack of health risk.

BEIs apply to 8-hour exposures, 5 days per week. Although modified work schedules are sometimes used in various occupations, the BEI Committee does not recommend that any adjustment or correction factor be applied to the BEIs (i.e., the BEIs should be used as listed, regardless of the work schedule).

Use of the BEI should be applied by a knowledgeable occupational health professional. Toxicokinetic and toxicodynamic information is taken into account when establishing the BEI; thus, some knowledge of the metabolism, distribution, accumulation, excretion, and effect(s) is helpful in using the BEI effectively. The BEI is a guideline for the control of potential health hazards to the worker and should not be used for other purposes. The values are inappropriate to use for the general population or for nonoccupational exposures. The BEI values are neither rigid lines between safe and dangerous concentrations nor are they an index of toxicity.

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

CHEMICAL [CAS #] *Determinant*	*Sampling Time*	*BEI*	*Notation*
ACETONE [67-64-1] (1999)			
Acetone in urine	End of shift	50 mg/L	Ns
ACETYLCHOLINESTERASE INHIBITING PESTICIDES (2000)			
Cholinesterase activity In red blood cells	Discretionary	70% of individual's baseline	B, Ns, Sq
ANILINE [62-53-3] (1991)			
Total p-aminophenol in urine	End of shift	50 mg/g creatinine	Ns
Methemoglobin in blood	During or end of shift	1.5% of hemoglobin	B, Ns, Sq
ARSENIC, ELEMENTAL [7440-38-2] AND SOLUBLE INORGANIC COMPOUNDS (2000)			
Inorganic arsenic plus methylated metabolites in urine	End of workweek	35 µg As/L	B
BENZENE [71-43-2]			
S-Phenylmercapturic acid in urine (1997)	End of shift	25 µg/g creatinine	B
t,t-Muconic acid in urine (2000)	End of shift	500 µg/g creatinine	B
CADMIUM AND INORGANIC COMPOUNDS (1993)			
Cadmium in urine	Not critical	5 µg/g creatinine	B
Cadmium in blood	Not critical	5 µg/L	B
CARBON DISULFIDE [75-15-0] (1988)			
2-Thiothiazolidine-4-carboxylic acid (TTCA) in urine	End of shift	5 mg/g creatinine	
CARBON MONOXIDE [630-08-0] (1993)			
Carboxyhemoglobin in blood	End of shift	3.5% of hemoglobin	B, Ns
Carbon monoxide in end-exhaled air	End of shift	20 ppm	B, Ns
CHLOROBENZENE [108-90-7] (1992)			
Total 4-chlorocatechol in urine	End of shift	150 mg/g creatinine	Ns
Total p-chlorophenol in urine	End of shift	25 mg/g creatinine	Ns
CHROMIUM (VI), Water-Soluble Fume (1990)			
Total chromium in urine	Increase during shift	10 µg/g creatinine	B
	End of shift at end of workweek	30 µg/g creatinine	B
COBALT [7440-48-4] (1995)			
Cobalt in urine	End of shift at end of workweek	15 µg/L	B
Cobalt in blood	End of shift at end of workweek	1 µg/L	B, Sq
N,N-DIMETHYLACETAMIDE [127-19-5] (1995)			
N-Methylacetamide in urine	End of shift at end of workweek	30 mg/g creatinine	

CHEMICAL [CAS #] *Determinant*	*Sampling Time*	*BEI*	*Notation*
N,N-DIMETHYLFORMAMIDE (DMF) [68-12-2] (1999)			
N-Methylformamide in urine	End of shift	15 mg/L	
N-Acetyl-S-(N-methylcarbamoyl) cysteine in urine	Prior to last shift of workweek	40 mg/L	Sq
2-ETHOXYETHANOL (EGEE) [110-80-5] and 2-ETHOXYETHYL ACETATE (EGEEA) [111-15-9] (1994)			
2-Ethoxyacetic acid in urine	End of shift at end of workweek	100 mg/g creatinine	
ETHYL BENZENE [100-41-4] (1986)			
Mandelic acid in urine	End of shift at end of workweek	1.5 g/g creatinine	.Ns
Ethyl benzene in end-exhaled air			Sq
FLUORIDES (1990)			
Fluorides in urine	Prior to shift	3 mg/g creatinine	B, Ns
	End of shift	10 mg/g creatinine	B, Ns
FURFURAL [98-01-1] (1991)			
Total furoic acid in urine	End of shift	200 mg/g creatinine	B, Ns
‡ n-HEXANE [110-54-3] (1987)			
‡ 2,5-Hexanedione in urine	(End of shift)	(5 mg/g creatinine)	Ns
n-Hexane in end-exhaled air			Sq
LEAD, Elemental, and Inorganic Salts (1998) [See Note below_]			
Lead in blood	Not critical	30 µg/100 ml	
Note: Women of child bearing potential, whose blood Pb exceeds 10 µg/dl, are at risk of delivering a child with a blood Pb over the current Centers for Disease Control guideline of 10 µg/dl. If the blood Pb of such children remains elevated, they may be at increased risk of cognitive deficits. The blood Pb of these children should be closely monitored and appropriate steps should be taken to minimize the child's exposure to environmental lead. (CDC: Preventing Lead Poisoning in Young Children, October 1991; See BEI and TLV *Documentations* for Lead).			
MERCURY (1993)			
Total inorganic mercury in urine	Preshift	35 µg/g creatinine	B
Total inorganic mercury in blood	End of shift at end of workweek	15 µg/L	B
METHANOL [67-56-1] (1995)			
Methanol in urine	End of shift	15 mg/L	B, Ns
METHEMOGLOBIN INDUCERS (1990)			
Methemoglobin in blood	During or end of shift	1.5% of hemoglobin	B, Ns, Sq
2-METHOXYETHANOL (EGME) [109-86-4] and 2-METHOXYETHYL ACETATE (EGMEA) [110-49-6] (1996)			
2-Methoxyacetic acid in urine	End of shift at end of workweek		Nq

CHEMICAL [CAS #] *Determinant*	*Sampling Time*	*BEI*	*Notation*
METHYL CHLOROFORM [71-55-6] (1989)			
Methyl chloroform in end-exhaled air	Prior to last shift of workweek	40 ppm	
Trichloroacetic acid in urine	End of workweek	10 mg/L	Ns, Sq
Total trichloroethanol in urine	End of shift at end of workweek	30 mg /L	Ns, Sq
Total trichloroethanol in blood	End of shift at end of workweek	1 mg/L	Ns
4,4'-METHYLENE BIS(2-CHLOROANILINE) [MBOCA] [101-14-4] (1997)			
Total MBOCA in urine	End of shift		Nq
METHYL ETHYL KETONE (MEK) [78-93-3] (1988)			
MEK in urine	End of shift	2 mg/L	
METHYL ISOBUTYL KETONE (MIBK) [108-10-1] (1993)			
MIBK in urine	End of shift	2 mg/L	
NITROBENZENE [98-95-3] (1991)			
Total p-nitrophenol in urine	End of shift at end of workweek	5 mg/g creatinine	Ns
Methemoglobin in blood	End of shift	1.5% of hemoglobin	B, Ns, Sq
PARATHION [56-38-2] (1989)			
Total p-nitrophenol in urine	End of shift	0.5 mg/g creatinine	Ns
Cholinesterase activity	Discretionary	70% of individual's baseline	B, Ns, Sq
PENTACHLOROPHENOL (PCP) [87-86-5] (1988)			
Total PCP in urine	Prior to last shift of workweek	2 mg/g creatinine	B
Free PCP in plasma	End of shift	5 mg/L	B
PHENOL [108-95-2] (1987)			
Total phenol in urine	End of shift	250 mg/g creatinine	B, Ns
STYRENE [100-42-5] (1986)			
Mandelic acid in urine	End of shift	800 mg/g creatinine	Ns
	Prior to next shift	300 mg/g creatinine	Ns
Phenylglyoxylic acid in urine	End of shift	240 mg/g creatinine	Ns
	Prior to next shift	100 mg/g creatinine	
Styrene in venous blood	End of shift	0.55 mg/L	Sq
	Prior to next shift	0.02 mg/L	Sq
TETRACHLOROETHYLENE [127-18-4] (1997)			
Tetrachloroethylene in end-exhaled air	Prior to last shift of workweek	5 ppm	
Tetrachoroethylene in blood	Prior to last shift of workweek	0.5 mg/L	
Trichloroacetic acid in urine	End of shift at end of workweek	3.5 mg/L	Ns, Sq

CHEMICAL [CAS #] *Determinant*	*Sampling Time*	*BEI*	*Notation*
TETRAHYDROFURAN [109-99-9] (2000)			
Tetrahydrofuran in urine	End of shift	8 mg/L	
TOLUENE [108-88-3] (1999)			
o-Cresol in urine	End of shift	0.5 mg/L	B
Hippuric acid in urine	End of shift	1.6 g/g creatinine	B, Ns
Toluene in blood	Prior to last shift of workweek	0.05 mg/L	
‡ TRICHLOROETHYLENE [79-01-6] (1986)			
‡ Trichloroacetic acid in urine	(End of workweek)	(100 mg/g creatinine)	Ns
‡ (Trichloroacetic acid and trichloroethanol in urine)	(End of shift at end of workweek)	(300 mg/g creatinine)	(Ns)
Free trichloroethanol in blood	End of shift at end of workweek	4 mg/L	Ns
‡ Trichloroethylene in blood (1993)	(—)	—	Sq
‡ Trichloroethylene in end-exhaled air	(—)	—	Sq
VANADIUM PENTOXIDE [1314-62-1] (1995)			
Vanadium in urine	End of shift at end of workweek	50 µg/g creatinine	Sq
XYLENES [13307] (Technical Grade) (1986)			
Methylhippuric acids in urine	End of shift	1.5 g/g creatinine	

NOTICE OF INTENT TO ESTABLISH OR CHANGE

These biological exposure indices (BEIs), with their corresponding values, comprise those for which a limit has been proposed or for which retention on the Notice of Intent to Establish or Change has been proposed. In each case, the proposed indices should be considered trial values that will remain in the listing for the year following ratification by the ACGIH Board of Directors. If, during the year, no evidence comes to light that questions the appropriateness of the values herein, the values will be reconsidered for Adoption. *Documentation* is available for each of these proposed BEIs.

CHEMICAL [CAS #] *Determinant*	*Sampling Time*	*BEI*	*Notation*
DICHLOROMETHANE (Methylene chloride) [75-09-2]			
Dichloromethane in blood	During shift	0.5 mg/L	
Dichloromethane in urine	End of shift	0.2 mg/L	Sq
† n-HEXANE [110-54-3]			
2,5-Hexanedione (free[A]) in urine	End of shift near end of workweek	4 mg/L	Ns[B]
† METHYL n-BUTYL KETEONE [591-78-6]			
2,5-Hexanedione (free[A]) in urine	End of shift near end of workweek	4 mg/L	Ns[B]

CHEMICAL [CAS #] *Determinant*	*Sampling Time*	*BEI*	*Notation*
† TRICHLOROETHYLENE [79-01-6]			
Trichloroacetic acid in urine	End of shift near end of workweek	100 mg/L	Ns
Trichloroethanol (free[A]) in blood	End of shift at end of workweek	4 mg/L	Ns
Trichloroethylene in blood	End of shift	—	Sq
Trichloroethylene in end-exhaled air	Prior to shift	—	Sq

[A]Without hydrolysis.
[B]Specific to hexane and methyl n-butyl ketone.

CHEMICAL SUBSTANCES AND OTHER ISSUES UNDER STUDY

The BEI Committee solicits information, especially data, which may assist it in its deliberations regarding the following substances and issues. Comments and suggestions, accompanied by substantive supporting data, should be forwarded to The Science Group, ACGIH. In addition, the Committee solicits recommendaitons for additional substances and issues of concern to the Industrial Hygiene and Occupational Health communities.

Chemical Substances

Acrylonitrile
Aluminum
Aniline
Antimony
Beryllium
1,3-Butadiene
2-Butoxyethanol
Carbon disulfide
Chromium
Cyclohexane and related compounds
2-Ethyl hexanoic acid
Fluorides
Furfural
Mercury
Methyl tert-butyl ether
Methyl formate
Nickel
Pentachlorophenol
Polynuclear aromatic hydrocarbons (PAHs)
2-Propanol
Pyrethrin
Pyrethrum
Styrene, monomer
Tetrachloroethylene
Uranium, natural
Vinyl chloride

Feasibility Assessment

For the substances listed below, the BEI Committee has determined that developing a BEI is not currently feasible owing to inadequate scientific data. However, the Committee believes that these substances may pose important risks to the health of workers, and therefore, it encourages the submission of new data. Field or experimental studies on the relationship between biological indicators and either health risk or environmental exposure are needed for these agents. A brief summary of the current negative feasibility assessment, including data needs, for each of the listed substances is available from The Science Group, ACGIH.

Substance	Date of Feasibility Assessment
Acrylonitrile	March 1994
Antimony	November 1996
Chlorpyrifos	October 1996
1,4-Dichlorobenzene	March 1994
2,4-Dichlorophenoxy-acetic acid	March 1994
Hydrazines	March 1994
Inorganic borates	October 1995
Manganese	April 1995
Methyl tert-butyl ether	October 1993
Methyl n-butyl ketone	October 1995
Nickel	November 1996
Selenium	November 1995
Trimethylbenzene	April 1999

Other Issues

1. Genetic and macromolecular markers of exposure.
2. Quality control in biological monitoring.
3. Methemoglobin inducers
4. Effect of physical exertion on body burden and the BEI.

2000 BIOLOGICAL EXPOSURE INDICES COMMITTEE

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2001

Biologically Derived Airborne Contaminants

Contents

BIOLOGICALLY DERIVED AIRBORNE CONTAMINANTS

Biologically derived airborne contaminants include bioaerosols (airborne particles composed of or derived from living organisms) and volatile organic compounds that organisms release. Bioaerosols include microorganisms (i.e., culturable, nonculturable, and dead microorganisms) and fragments, toxins, and particulate waste products from all varieties of living things. Biologically derived contaminants are ubiquitous in nature and may be modified by human activity. Humans are repeatedly exposed, day after day, to a wide variety of such materials.

TLVs exist for certain substances of biological origin, including cellulose; some wood, cotton, flour and grain dusts; nicotine; pyrethrum; starch; subtilisins (proteolytic enzymes); sucrose; vegetable oil mist; and volatile compounds produced by living organisms (e.g., ammonia, carbon dioxide, ethanol, and hydrogen sulfide). However, for the reasons identified below, there are no TLVs against which to compare environmental air concentrations of most materials of biological origin.

ACGIH has developed and separately published guidance on the assessment, control, remediation, and prevention of biologically derived contamination in indoor environments.[1] Indoor biological contamination is defined as the presence of a) biologically derived aerosols, gases, and vapors of a kind and concentration likely to cause disease or predispose people to disease; b) inappropriate concentrations of outdoor bioaerosols, especially in buildings designed to prevent their entry; or c) indoor microbial growth and remnants of biological growth that may become aerosolized and to which people may be exposed. The term biological agents refers to a substance of biological origin that is capable of producing an adverse effect, e.g., an infection or a hypersensitivity, irritant, inflammatory, or other response.

The ACGIH-recommended approach to assessing and controlling bioaerosol exposures relies on visually inspecting building, assessing occupant symptoms, evaluating building performance, monitoring potential environmental sources, and applying professional judgment. The published guidance provides background information on the major groups of bioaerosols, including their sources and health effects, and describes methods to collect, analyze, and interpret bioaerosol samples from potential environmental sources. Occasionally, environmental monitoring detects a single or predominating biological contaminant. More commonly, monitoring reveals a mixture of many biologically derived materials, reflecting the diverse and interactive nature of indoor microenvironments. Therefore, environmental sampling for bioaerosols should be conducted only following careful formulation of testable hypotheses about potential bioaerosol sources and mechanisms by which workers may be exposed to bioaerosols from these sources. Even when investigators work from testable hypotheses and well-formulated sampling plans, results from environmental bioaerosol monitoring may be inconclusive and occasionally misleading.

There are no TLVs for interpreting environmental measurements of a) total culturable or countable bioaerosols (e.g., total bacteria or fungi); b) specific culturable or countable bioaerosols (e.g., *Aspergillus fumigatus*); c) infectious agents (e.g., *Legionella pneumophila* or *Mycobacterium tuberculosis*); or d) assayable biological contaminants (e.g., endotoxin, mycotoxin, antigens, or microbial volatile organic compounds) for the following reasons.

A. Total culturable or countable bioaerosols. Culturable bioaerosols are those bacteria and fungi that can be grown in laboratory culture. Such results are reported as the number of colony-forming units (CFU). Countable bioaerosols are those pollen grains, fungal spores, bacterial cells, and other material that can be identified and counted by microscope. A general TLV for culturable or countable bioaerosol concentrations is not scientifically supportable because of the following:

1. Culturable microorganisms and countable biological particles do not comprise a single entity, i.e., bioaerosols in occupational settings are generally complex mixtures of many different microbial, animal, and plant particles.
2. Human responses to bioaerosols range from innocuous effects to serious, even fatal, diseases, depending on the specific material involved and workers' susceptibility to it. Therefore, an appropriate exposure limit for one bioaerosol may be entirely inappropriate for another.
3. It is not possible to collect and evaluate all bioaerosol components using a single sampling method. Many reliable methods are available to collect and analyze bioaerosol materials. However, different methods of sample collection and analysis may result in different estimates of culturable and countable bioaerosols

concentrations.

4. At present, information relating culturable or countable bioaerosol concentrations to health effects is generally insufficient to describe exposure–response relationships.

B. Specific culturable or countable bioaerosols other than infectious agents. Specific TLVs for individual culturable or countable bioaerosols have not been established to prevent hypersensitivity, irritant, or toxic responses. At present, information relating culturable or countable bioaerosol concentrations to health effects consists largely of case reports and qualitative exposure assessments. The data available are generally insufficient to describe exposure–response relationships. Reasons for the absence of good epidemiologic data on such relationships include the following.

1. Most data on concentrations of specific bioaerosols are derived from indicator measurements rather than from measurements of actual effector agents. For example, investigators use the air concentration of culturable fungi to represent exposure to airborne fungal antigens. In addition, most measurements are from either area or source samples. These monitoring approaches are less likely to reflect human exposure accurately than would personal sampling for actual effector agents.
2. Bioaerosol components and concentrations vary widely within and among different occupational and environmental settings. Unfortunately, replicate sampling is uncommon in bioaerosol assessments. Further, the most commonly used air-sampling devices for indoor monitoring are designed to collect "grab" samples over relatively short time intervals. Measurements from single, short-term grab samples may be orders of magnitude higher or lower than long-term average concentrations and are unlikely to represent workplace exposures accurately. Some organisms and sources release aerosols as "concentration bursts," which may only rarely be detected by limited grab sampling. Nevertheless, such episodic bioaerosol releases may produce significant health effects.

C. Infectious agents. Human dose–response data are available for only a few infectious bioaerosols. At present, air-sampling protocols for infectious agents are limited and suitable primarily for research endeavors. In most routine exposure settings, public health measures, such as immunization, active case finding, and medical treatment, remain the primary defenses against infectious bioaerosols. Facilities associated with increased risks for transmission of airborne infectious diseases (e.g., microbiology laboratories, animal-handling facilities, and health-care settings) should employ engineering controls to minimize air concentrations of infectious agents. Further, such facilities should consider the need for administrative controls and personal protective equipment to prevent the exposure of workers to these bioaerosols.

D. Assayable biological contaminants. Assayable, biologically derived contaminants (e.g., endotoxin, mycotoxins, antigens, and volatile organic compounds) are microbial, animal, or plant substances that can be detected using chemical, immunological, or biological assays. Evidence does not yet support TLVs for any of these substances. However, assay methods for certain common airborne antigens and endotoxin are steadily improving, and field validation of these assays is also progressing. Dose–response relationships for some assayable bioaerosols have been observed in experimental studies and occasionally in epidemiologic surveys. Therefore, exposure limits for certain assayable, biologically derived, airborne contaminants may be appropriate in the future. In addition, innovative molecular techniques are becoming available for specific bioaerosols currently detectable only by culture or counting.

ACGIH actively solicits information, comments, and data on health effects associated with bioaerosol exposures in occupational and related environments that may help the Bioaerosols Committee evaluate the potential for proposing exposure guidelines for selected biologically derived airborne contaminants. Such information should be sent, preferably in electronic format, to The Science Group, ACGIH.

Reference

1. American Conference of Governmental Industrial Hygienists: Bioaerosols: Assessment and Control. J.M. Macher, Ed.; H.M. Ammann, H.A. Burge, D.K. Milton, and P.R. Morey, Asst. Eds. ACGIH, Cincinnati, Oh (1999).

BIOLOGICALLY DERIVED AGENTS UNDER STUDY

The Bioaerosols Committee solicits information, especially data, which may assist it in the establishment of TLVs for biologically derived airborne contaminants. Comments and suggestions, accompanied by substantive supporting data, should be forwarded, preferably in electronic format, to The Science Group, ACGIH.

Agents

Gram negative bacterial endotoxin
(1-3) beta, D-glucan1-

2000 BIOAEROSOLS COMMITTEE

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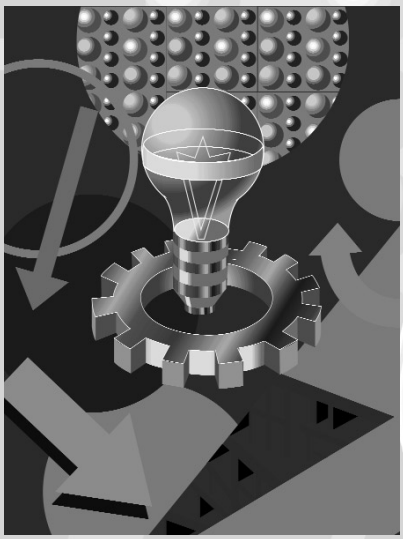
ENDNOTES

* 2001 Adoption.
‡ See Notice of Intended Changes.
( ) Adopted values enclosed are those for which changes are proposed. Consult the Notice of Intended Changes for current proposal.
† 2001 Revision or Addition to the Notice of Intended Changes.
A Refers to Appendix A: Carcinogens.
B Refers to Appendix B: Substances of Variable Composition.
C Ceiling limit; see definition in the "Introduction to the Chemical Substances."
(D) *See* definition in the "Introduction to the Chemical Substances."
(E) The value is for particulate matter containing no asbestos and < 1% crystalline silica.
(F) Respirable fibers: length > 5 µm; aspect ratio ≥ 3:1, as determined by the membrane filter method at 400 to 450× magnification (4-mm objective), using phase-contrast illumination.
(G) As measured by the vertical elutriator, cotton-dust sampler. *See* TLV Documentation
(H) Aerosol only
(I) Inhalable fraction; *see* Appendix D, paragraph A.
(J) Does not include stearates of toxic metals.
(K) Should not exceed 2 mg/m^3 respirable dust.
(L) Exposure by all routes should be carefully controlled to levels as low as possible.
(M) Classification refers to sulfuric acid contained in strong inorganic acid mists
(N) Except castor cashew nut, or similar irritant oils.
(P) Sampled by method that does not collect vapor.
(R) Respirable fraction; *see* Appendix D, paragraph C.
(T) Thoracic fraction; *see* Appendix D, paragraph B.
(V) Vapor and aerosol.

BEI = Substances for which there are also BEIs (*see* BEI section). Substances identified as Methemoglobin Inducers (for which methemoglobin is the principal cause of toxicity) and as Acetylcholinesterase Inhibiting Pesticides are part of this notation.
CNS = Central nervous system
CVS = Cardiovascular system
GI = Gastrointestinal
MW = Molecular weight
NOS = Not otherwise specified
SEN = Sensitizer; *see* definition in the "Introduction to the Chemical Substances."
Skin = Danger of cutaneous absorption; *see* discussion in the "Introduction to the Chemical Substances."
STEL = Short-term exposure limit; *see* definition in the "Introduction to the Chemical Substances."
TWA = 8-hour, time-weighted average; *see* definition in the "Introduction to the Chemical Substances."
ppm = Parts of vapor or gas per million parts of contaminated air by volume at NTP conditions (25°C; 760 torr).
mg/m^3 = Milligrams of substance per cubic meter of air.



Conversion of Units

Appendix C

Appendix C
Conversion of Units

All physical units of measurement can be reduced to one or more of three dimensions: mass, length, and time. Reducing units to basic dimensions simplifies problem solving and makes comparison between operations, or operations and standards, easier and more accurate.

For example, three airflows could be measured: the first in liters per second, the second in cubic meters per second, and the third in cubic feet per minute. Then the total volume of air in each of the three samplings could be converted to cubic meters or cubic feet, and the airflows could be compared. In another situation, the results of atmospheric pollution studies and stack sampling surveys are often reported as grains per cubic foot, grams per cubic foot, or pounds per cubic foot. The degree of contamination is usually reported in the standard unit of parts of contaminant per million parts of air.

If physical measurements are made or reported in different units, they must be converted to the standard units if any comparisons are to be meaningful.

In order to achieve a uniform system of measurement, governments representing 98 percent of the world's population have committed to using the Système International d'Unités *(SI) version of the metric system (McQueen MJ. Conversion to SI units; The Canadian experience.* JAMA *256:3001–3002, 1986.) In 1975, Congress passed the Metric Conversion Act, which endorsed a voluntary conversion to SI, but the English system is still in popular use in the United States. The SI system, however, is the standard for the international scientific community.*

FUNDAMENTAL UNITS

Because of the need to conserve time and space when reporting data, universally accepted abbreviations are often used in place of unit names. This appendix shows the abbreviations used throughout this book and those gener-

ally agreed on by industrial hygiene practitioners. Conversion factors are provided when data are reported in nonstandard units.

Each measurement unit, such as length, area, and flow, has a table of conversion factors. To use the table to find the numerical value of the quantity desired, locate the unit to be converted in the first column. Then multiply this value by the number appearing at the intersection of the row and the column containing the desired unit. The answer will be the numerical value in the desired unit. Various English system and metric system units are given for your convenience.

An explanation of the SI system and official conversion factors are given to a 6- or 7-place accuracy in ASTM standard E380-76 (ANSI Z210.1-1976). (This standard is available, although not listed in the ANSI Catalog.)

Table C–A. ***Base Système International (SI) Units***

Physical Quantity	*Base Units*	*SI Symbol*
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Amount of substance	Mole	mol
Thermodynamic temperature	Kelvin	K
Electric current	Ampere	A
Luminous intensity	Candela	cd

Table C–B. ***Units Derived from Combinations of Base Units***

Derived Unit	*Name and Symbol*	*Expressed as SI Base Derived Unit*
Area	Square meter	m^2
Volume	Cubic meter	m^3
Force	Newton (N)	$kg \cdot m \cdot s^{-2}$ ($kg \cdot m/s^2$)
Frequency	Hertz (Hz)	s^{-1}
Work, energy, heat	Joule (J)	$N \cdot m$
Power	Watt (W)	$J \cdot s^{-1}$(J/S)
Pressure	Pascal (Pa)	$kg \cdot m^{-1} \cdot s^{-2}$($N/m^2$)
Electric potential	Volt (V)	$W \cdot A^{-1}$(W/A)
Electric charge	Coulomb (C)	$A \cdot s$
Electric capacitance	Farad (F)	$A \cdot sV^{-1}$(A s/V or C/N)
Inductance	Henry (H)	$V \cdot s \cdot A^{-1}$ ($V \cdot s/A$)

Table C–C. ***Multiples and Submultiples of SI Units***

Factor	*Prefix*	*Symbol*
10^{12}	tetra	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	P
10^{-15}	femto	f
10^{-18}	atto	a

Tables C–A through C–C are reprinted with permission from *JAMA* 256(21) Dec. 5, 1986, pp. 3001–3002, ©1986, American Medical Association.

Table C–D. ***Area***

To Obtain → / *Multiply Number of* ↓ *by* ↘	*Square Meter (m^2)*	*Square Inch ($in.^2$)*	*Square Foot (ft^2)*	*Square Centimeter (cm^2)*	*Square Millimeter (mm^2)*
Square meter	1	1,550	10.76	10,000	10^6
Square inch	6.452×10^{-3}	1	6.94×10^{-3}	6.452	645.2
Square foot	0.0929	144	1	929.0	92,903
Square centimeter	0.0001	0.115	0.001	1	100
Square millimeter	10^{-6}	0.00155	0.00001	0.01	1

Table C–E. ***Length***

To Obtain → / *Multiply Number of ↓* *by ↘*	*Meter (m)*	*Centimeter (cm)*	*Millimeter (mm)*	*Micron (μ) or Micrometer*	*Angstrom Unit (Å)*	*Inch (in.)*	*Foot (ft)*
Meter	1	100	1,000	10^6	10^{10}	39.37	3.28
Centimeter	0.01	1	10	10^4	10^8	0.394	0.0328
Millimeter	0.001	0.1	1	10^3	10^7	0.0394	0.00328
Micron	10^{-6}	10^{-4}	10^{-3}	1	10^4	3.94×10^{-5}	3.28×10^{-6}
Angstrom	10^{-10}	10^{-8}	10^{-7}	10^{-4}	1	3.94×10^{-9}	3.28×10^{-10}
Inch	0.0254	2.540	25.40	2.54×10^4	2.54×10^8	1	0.0833
Foot	0.305	30.48	304.8	304,800	3.048×10^9	12	1

Table C–F. ***Density***

To Obtain → / *Multiply Number of ↓* *by ↘*	*gm/cm³*	*lb/ft³*	*lb/gal*
Gram/cubic centimeter	1	62.43	8.345
Pound/cubic foot	0.01602	1	0.1337
Pound/gallon (U.S.)	0.1198	7.481	1

1 grain/ft³ = 2.28 mg/m³

Table C–G. ***Force***

To Obtain → / *Multiply Number of ↓* *by ↘*	*Dyne*	*Newton (N)*	*Kilogram-Force*	*Pound-Force (lbf)*
Dyne	1	1.0×10^{-5}	1.02×10^4	2.248×10^4
Newton	1.0×10^5	1	0.1020	0.2248
Kilogram-force	9.807×10^{-5}	9.807	1	2.205
Pound-force	4.448×10^{-5}	4.448	0.4536	1

Table C–H. ***Mass***

To Obtain → / *Multiply Number of ↓* *by ↘*	*Gram (gm)*	*Kilogram (kg)*	*Grains (gr)*	*Ounce (avoir) (oz)*	*Pound (avoir) (lb)*
Gram	1	0.001	15.432	0.03527	0.00220
Kilogram	1,000	1	15,432	35.27	2.205
Grain	0.0648	6.480×10^{-5}	1	2.286×10^{-3}	1.429×10^{-4}
Ounce	28.35	0.02835	437.5	1	0.0625
Pound	453.59	0.4536	7,000	16	1

Table C–I. ***Volume***

To Obtain → / *Multiply Number of* ↓ *by* ↘	ft^3	Gallon (U.S. Liquid)	Liters	cm^3	m^3
Cubic foot	1	7.481	28.32	28,320	0.0283
Gallon (U.S. liquid)	0.1337	1	3.785	3,785	3.79×10^{-3}
Liter	0.03531	0.2642	1	1,000	1×10^{-3}
Cubic centimeters	3.531×10^{-5}	2.64×10^{-4}	0.001	1	10^{-6}
Cubic meters	35.31	264.2	1,000	10^6	1

Table C–J. ***Velocity***

To Obtain → / *Multiply Number of* ↓ *by* ↘	*cm/s*	*m/s*	*km/hr*	*ft/s*	*ft/min*	*mph*
Centimeter/second	1	0.01	0.036	0.0328	1.968	0.02237
Meter/second	100	1	3.6	3.281	196.85	2.237
Kilometer/hour	27.78	0.2778	1	0.9113	54.68	0.6214
Foot /second	30.48	0.3048	18.29	1	60	0.6818
Foot /minute	0.5080	0.00508	0.0183	0.0166	1	0.01136
Mile per hour	44.70	0.4470	1.609	1.467	88	1

Table C–K. ***Flow Rates***

To Obtain → / *Multiply Number of* ↓ *by* ↘	*Lmin*	m^3/s	m^3/hr	*gal/min*	ft^3/min	ft^3/s
Liter/minute	1	1.67×10^{-5}	0.06	0.2640	0.0353	5.89×10^{-4}
Cubic meters/second	4.63×10^{-3}	1	2.77×10^{-4}	1.22×10^{-3}	1.63×10^{-4}	2.7×10^{-6}
Cubic meter/hour	16.67	2.78×10^{-4}	1	4.4	0.588	9.89×10^{-3}
Gallon (U.S.)/minute	3.78	6.3×10^{-5}	0.227	1	0.1338	2.23×10^{-3}
Cubic foot /minute	28.32	4.71×10^{-4}	1.699	7.50	1	0.01667
Cubic foot /second	1.69×10^3	2.83×10^{-3}	1.02×10^2	448.8	60	1

Table C–L. ***Heat, Energy, or Work***

To Obtain → / *Multiply Number of* ↓ *by* ↘	*Joule*	*ft-lb*	*kwh*	*hp-hour*	*kcal*	*cal*	*Btu*
Joules	1	0.737	2.773×10^{-7}	3.725×10^{-7}	2.39×10^{-4}	0.2390	9.478×10^{-4}
Foot-pound	1,356	1	3.766×10^{-7}	5.05×10^{-7}	3.24×10^{-4}	0.3241	1.285×10^{-3}
Kilowatt-hour	3.6×10^6	2.66×10^6	1	1.341	860.57	860,565	3,412
Hp-hour	2.68×10^6	1.98×10^6	0.7455	1	641.62	641,615	2,545
Kilocalorie	4,184	3,086	1.162×10^{-3}	1.558×10^{-3}	1	1,000	3.9657
Calorie	4.184	3.086	1.162×10^{-6}	1.558×10^{-6}	0.001	1	0.00397
British thermal unit	1,055	778.16	2.930×10^{-4}	3.93×10^{-4}	0.252	252	1

Table C–M. ***Emission Rates***

To Obtain → / *Multiply Number of ↓ by ↘*	*gm/s*	*gm/min*	*kg/hr*	*kg/day*	*lb/min*	*lb/hr*	*lb/day*
Gram/second	1.0	60.0	3.6	86.40	0.13228	7.9367	190.48
Gram/minute	0.016667	1.0	0.06	1.4400	2.2046×10^{-3}	0.13228	3.1747
Kilogram/hour	0.27778	16.667	1.0	24.000	0.036744	2.2046	52.911
Kilogram/day	0.011574	0.69444	0.041667	1.0	1.5310×10^{-3}	9.1860×10^{-2}	2.2046
Pound/minute	7.5598	453.59	27.215	653.17	1.0	60.0	1440
Pound/hour	0.12600	7.5598	0.45359	10.886	1.6667×10^{-2}	1.0	24.0
Pound/day	5.2499×10^{-3}	0.31499	1.8900×10^{-2}	0.45359	6.9444×10^{-4}	4.1667×1^{-2}	1.0

Table C–N. ***Pressure***

To Obtain → / *Multiply Number of ↓ by ↘*	*lb/in.^{2} (psi)*	*atm*	*in. (Hg) 32 F 0 C*	*mm (Hg) 32 F 0 C*	*k Pa (k N/m^2)*	*ft (H_20) 60 F 15 C*	*in. (H_20)*	*lb/ft^2*
Pound/square inch	1	0.068	2.036	51.71	6.895	2.309	27.71	144
Atmospheres	14.696	1	29.92	760.0	101.32	33.93	407.2	2,116
Inch (Hg)	0.4912	0.033	1	25.40	3.386	1.134	13.61	70.73
Millimeter (Hg)	0.01934	0.0013	0.039	1	0.1333	0.04464	0.5357	2.785
Kilopascals	0.1450	9.87×10^{-3}	0.2953	7.502	1	0.3460*	4.019	20.89
Foot (H_20)(15 C)	0.4332	0.0294	0.8819	22.40	2.989*	1	12.00	62.37
Inch (H_20)	0.03609	0.0024	0.073	1.867	0.2488	0.0833	1	5.197
Pound/square foot	0.0069	4.72×10^{-4}	0.014	0.359	0.04788	0.016	0.193	1

* at 4 C

Table C–O. ***Radiant Energy Units***

To Obtain → / *Multiply ↓ by ↘*	*Erg*	*Joule (J)*	*W-s*	*μW-s*	*g-cal*
Erg	1	10^{-7}	10^{-7}	0.1	2.39×10^{-8}
Joule	10^7	1	1	10^6	0.239
Watt-second	10^7	1	1	10^6	0.239
Microwatt-second	10	10^{-6}	10^{-6}	1	2.39×10^{-7}
Gram-calorie	4.19×10^7	4.19	4.19	4.19×10^6	1

Table C–P. ***Energy/Unit Area (Dose Units)***

To Obtain → / *Multiply ↓ by ↘*	*erg/cm^2*	*J/cm^2*	*W-s/cm^2*	*μW-s/cm^2*	*g-cal/m^2*
Erg/square centimeter	1	10^{-7}	10^{-7}	0.1	2.39×10^{-8}
Joule/square centimeter	10^7	1	1	10^6	0.239
Watt-second/square centimeter	10^7	1	1	10^6	0.239
Microwatt-second/square centimeter	10	10^{-6}	10^{-6}	1	2.39×10^{-7}
Gram-calorie/square centimeter	4.19×10^7	4.19	4.19	4.19×10^6	1

Table C–Q. ***Temperature Equivalents***

Scale	*Symbol*	*Freezing Point of Water (1 atm)*	*Boiling Point of Water (1 atm)*
Celsius	C	0	100 deg
Fahrenheit	F	32	212
Thermodynamic Kelvin Absolute Celsius	K, A	273.16 ± 0.01*	373.16 ± 0.01*
Approximate absolute	AA	273	373
Rankine Absolute Fahrenheit	R	491.69	671.69

Conversion formulae

$$C = (5/9)(F - 32) = K - 273.16 = AA - 273$$

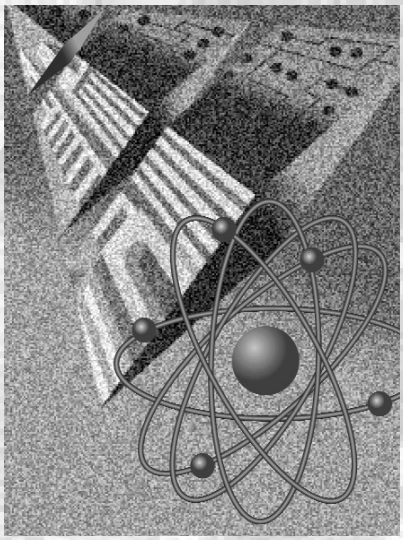
$$F = (9/5)C + 32 = (9/5)(K - 273.16) + 32$$

$$K = C + 273.16 = AA + 0.16 = (5/9)(F - 32) + 273.16$$

$$AA = C + 273 = K - 0.16 = (5/9)(F - 32) + 273$$

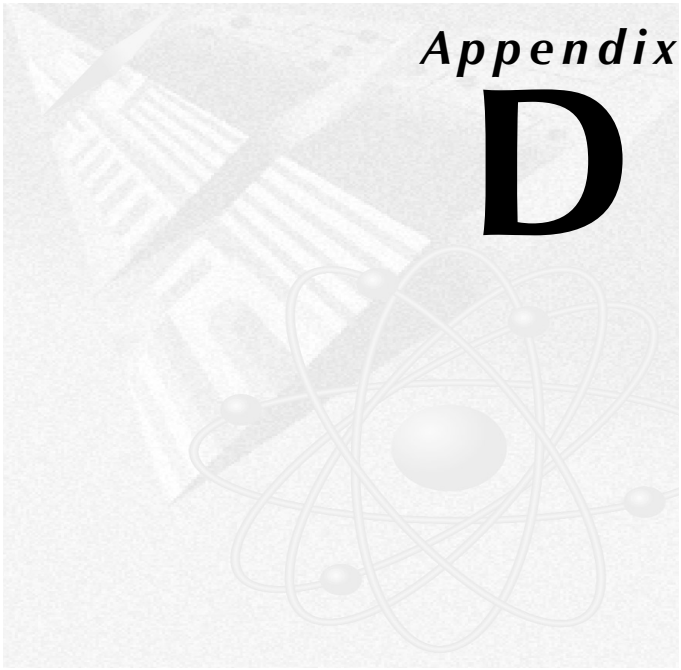
$$\text{Rankine} = F + 459.69$$

(From Birge RT, *Rev Mod Phys* 13:233, 1941.)



Review of Mathematics

Appendix D



Appendix D Review of Mathematics

SIGNIFICANT FIGURES

Measurements often result in what are called *approximate numbers,* in contrast to *discrete counts.* For example, the dimensions of a table can be reported as 29.6 in. (75.2 cm) by 50.2 in. (127.5 cm). This implies that the measurement is to the nearest tenth of an inch (or centimeter) and that the table is less than 50.25 in. (127.6 cm) and more than 50.15 in. (127.4 cm) in length. One can show the same thing for the width, using the following symbolic notations:

$$75.0 \text{ cm } (29.55 \text{ in.}) < \text{width} < 75.3 \text{ cm } (29.65 \text{ in.})$$

If, on the other hand, one knows the degree of precision of the measurement (say, 0.03 cm or ± 0.08 cm), one may write:

$$50.2 \pm 0.3 \text{ or } 50.2 \pm 0.8$$

to indicate the degree of accuracy of the measurement of the length.

In reporting results, the number of significant digits that can be recorded is determined by the precision of the instruments used.

Rules

- In any approximate number, the *significant digits* include the digit that determines the degree of precision of the number and all digits to the left of it, except for zeros used to place the decimal.
- All digits from 1 to 9 are significant.
- All zeros between significant digits are significant.
- Final zeros of decimal numbers are significant. For example:

Number	Number of Significant Digits
0.0702	3
0.07020	4
70.20	4
7,002	4
7,020	3

Scientific Notation

One case where it is difficult to determine the number of significant digits is the figure 7,000. In general, it is considered to have only one significant digit. It is better to use scientific notation.

In standard scientific notation, the number is written as a number between 1 and 10, in which only the significant digits are shown, multiplied by an exponential number to the base 10. For example:

Number	Number of Significant Digits
$5{,}320{,}000 = 5.32 \times 10^6$	3
$= 5.320 \times 10^6$	4
$= 5.3200 \times 10^6$	5
$0.00000532 = 5.32 \times 10^{-6}$	3

Addition and Subtraction

The result must not have more decimal places than the number with the fewest decimal places. For example:

21.262	should be	21.3
23.74	should be	23.7
139.6	should be	139.6
184.602	should be	184.6

Multiplication and Division

The result must not have more significant places than are possessed by the number with the fewest significant digits. For example:

$$\begin{aligned}(50.20)(29.6) &= 1485.92\\ &= 1490\\ &= 1.49 \times 10^3\end{aligned}$$

LOGARITHMS

Logarithms are exponents. The logarithm of any number is the power to which a selected base must be raised to produce the number. The laws of exponents apply to logarithms.

The following two equations:

$$a^x = y$$

and

$$x = \log_a y$$

are two ways of expressing the same thing, that is, the exponent applied to a to give y is equal to x. The value a is called the base of the system of logarithms.

Although any positive number greater than 1 can be used as the base of some system of logarithms, there are two systems in general use. These are the *common* (or Briggs') system and the *natural* (or Napierian) system. In the common system, the base is 10; in the natural system, the base is the irrational number e = 2.71828 . . .

Common Logarithms

Common logarithms use the base 10 and are identified by the notation *log*. The common logarithm of a number consists of a characteristic, which locates the decimal point in the number, and a mantissa, which defines the numerical arrangement of the number.

A bar over a characteristic indicates a negative characteristic and a positive mantissa. The log may be written $\overline{4}.7$or 6.7 – 10 or –3.3. The form –3.3 does not contain a characteristic and mantissa.

The integral part of a logarithm is called the *characteristic* and the decimal part is called the *mantissa*. In log 824, the characteristic is 2 and the mantissa is 0.9162. For convenience in constructing tables, it is desirable to select the mantissa as positive even if the logarithm is a negative number. For example, log 1/2 = –0.3010; but because –0.3010 = 9.6990 – 10, this may be written log 1/2 = 9.6990 – 10 with a positive mantissa. This is also the log of 0.5, which we could have looked up in the first place. The following illustration shows the method of writing the characteristic and mantissa:

$$\begin{aligned}\log\ 8245 &= 3.9162\\ \log\ 824.5 &= 2.9162\\ \log\ 82.45 &= 1.9162\\ \log\ 8.245 &= 0.9162\\ \log\ 0.8245 &= 9.9162–10\\ \log\ 0.08245 &= 8.9162–10\end{aligned}$$

By using scientific notation, we can easily find logarithm characteristics, as shown in the table in the next section.

How to Use Logarithms

If the laws of exponents are rewritten in terms of logarithms, they become the *laws of logarithms:*

$$\log_a(x^n) = n \log_a x$$

$$\log_a\left(\frac{x}{y}\right) = \log_a x – \log_a y$$

$$\log_a(x^a) = n \log_a x$$

Logarithms derive their main usefulness in computation from these laws because they allow multiplication, division, and exponentiation to be replaced by the simpler operations of addition, subtraction, and multiplication, respectively.

		Common Logarithmic Form		
Number	Exponential Form	Characteristic	Mantissa	Complete Log
0.0005	5×10^{-4}	–4	0.7	$\overline{4}.7$
0.05	5×10^{-2}	–2	0.7	$\overline{2}.7$
5.0	5×10^{0}	0	0.7	0.7
500.0	5×10^{2}	2	0.7	2.7
50,000.0	5×10^{4}	4	0.7	4.7

How to Use Logarithm Tables

In this appendix is a four-place table of logarithms. In this table, the mantissas of the logarithms of all integers from 1 to 999 are recorded correct to four decimal places, which is all one needs to work with decibels, which have three significant digits at most.

To find the logarithm of a given number, use the table as follows: To find the logarithm of 63.5, glance down the column headed *N* for the first two significant digits (63), and then along the top of the table for the third figure (5). In the row across from 63 and in the column under 5 is found 8028. This is the mantissa. Adding the proper characteristic 1, the logarithm (or log) of 63.5 is 1.8028.

Conversely, one can find the number that corresponds to a given logarithm (the antilogarithm). For example, find the number whose logarithm is 1.6355. The mantissa 6355 corresponds to the number in the table that is in the column below 2 and in the row across from 43. Thus, the mantissa corresponds to the number 432. Because the characteristic is 1, the number whose logarithm is 1.6355 is 43.2.

Because in measuring sound we are concerned only with three significant digits, the number whose logarithm is 1.6360 would also be 43.2. The number whose logarithm is 1.6361 would be 43.3.

Decibel Notation

Again, using the measurement of sound as an example, if two sound intensities P_1 and P_2 are to be compared according to the ability of the ear to detect intensity differences, we may determine the number of decibels that expresses the relative value of the two intensities by

$$N_{\text{dB}} = 10 \log_{10} \frac{P_1}{P_2}$$

where P_1 is greater than P_2.

The factor 10 comes into this picture because the original unit devised was the *bel,* which is the logarithm of 10 to the base 10 and represents 10 times as many decibels in any expression involving the relation between two sound intensities as there are bels.

The decibel is a logarithmic unit. Each time the amount of power is increased by a factor of 10, we have added 10 decibels (abbreviated dBA).

To determine the number of decibels by which two powers differ, we must *first determine the ratio of the two powers;* we look up this ratio in a table of logarithms to the base 10 and then we multiply the figure obtained by a factor of 10.

If we want to find the relative loudness of 10,000 people who can shout louder than 100 people can, we use the following reasoning.

The logarithm (to the base 10) of any number is merely the number of times 10 must be multiplied by itself to be equal to the number. In the example here, 100 represents 10 multiplied by itself, and the logarithm of 100 to the base 10, therefore, is 2. For example, the number of decibels expressing the relative loudness of 10,000 people shouting compared with 100 is

$$\begin{aligned} N_{\text{dB}} &= 10 \log_{10}(10{,}000 \div 100) \\ &= 10 \log_{10} 100 \\ &= 10 \times 2.0 \\ &= 20 \end{aligned}$$

Now let us see what happens if we double the number of people to 20,000.

$$\begin{aligned} N_{\text{dB}} &= 10 \log_{10}(20{,}000 \div 100) \\ &= 10 \log_{10} 200 \\ &= 10 \times 2.3010 \\ &= 23 \text{ (rounded to significant digits)} \end{aligned}$$

It can be seen, therefore, that decibels are logarithm ratios. In their use in sound measurement, *P* (the usual reference level) is 20 micropascals or 0.0002 dynes/square centimeter, which approximates the threshold of hearing, the sound that can just be heard by a young person with excellent hearing.

NORMAL AND LOGNORMAL FREQUENCY DISTRIBUTIONS

The statistical methods discussed here assume that measured concentrations of random occupational environmental samples are lognormally and independently distributed within one 8-hour period and over many daily exposure averages.

Before sample data can be statistically analyzed, we must have knowledge of the frequency distribution of the measurements or some assumptions must be made. Most community air pollution environmental data can be described by a lognormal distribution. That is, the logarithms (either base e or base 10) of the data are approximately normally distributed.

What are the differences between normally and lognormally distributed data? A normal distribution is completely determined by the parameters: the arithmetic mean (μ); the standard deviation (σ) of the distribution. A lognormal distribution is completely determined by the median or geometric mean (GM) and the geometric standard deviation (GSD). For lognormally distributed data, a logarithmic transformation of the original data is normally distributed. The GM and GSD of the lognormal distribution are the antilogs of the mean and standard deviation of the logarithmic

transformation. Normally distributed data have a symmetrical distribution curve whereas lognormally distributed environmental data are generally positively skewed (long "tail" to the right indicating a larger probability of very large concentrations than for normally distributed data.)

Variability

The variability of occupational environmental data (differences between repeated measurements at the same site) can usually be broken into three major components: random errors of the sampling method, random errors of the analytical method, and variability of the environment with time. The first two components of the variability are known in advance and are approximately normally distributed. However, the environmental fluctuations of a contaminant in a facility usually greatly exceed the variability of known instruments (often by factors of 10 or 20).

When several samples are taken in a facility to determine the average concentration of the contaminant to estimate the average exposure of an employee, then the lognormal distribution should be assumed. However, the normal distribution may be used in the special cases of taking a sample to check compliance with a ceiling standard, and when a sample (or samples) is taken for the entire time period for which the standard is defined (be it 15 minutes or 8 hours). In these cases, the entire time interval of interest is represented in the sample, and only sampling and analytical errors are present.

Coefficient of Variation

The relative variability of a normal distribution (such as the random errors of the sampling and analytical procedures) is commonly measured by the coefficient of variation (CV). The CV is also known as the *relative standard deviation*. The CV is a useful index of dispersion in that limits consisting of the true mean of a set of data plus or minus twice the CV will contain about 95 percent of the data measurements.

Thus, if an analytical procedure with a CV of 10 percent is used to repeatedly measure some nonvarying physical property (as the concentration of a chemical in a beaker of solution), then about 95 percent of the measurements will fall within plus or minus 20 percent (two times the CV) of the true concentration.

EXPOSURE CONCENTRATION

Unfortunately, the property we are trying to measure, the employee's exposure concentration, is not a fixed, nonvarying physical property. The exposure concentrations are fluctuating in a lognormal manner. First, the exposure concentrations are fluctuating over the 8-hour period of the time-weighted average (TWA) exposure measurement. Breathing zone grab samples (samples of less than about 30 minutes' duration, typically only a few minutes) tend to reflect this intraday environmental variability so that grab sample results have relatively high variability.

Intraday variability in the sample results can be eliminated from measurement variability by going to a full-period sampling strategy. The day-to-day (interday) variability of the true 8-hour TWA exposures is also lognormally distributed. This interday variability creates a need for an action level where only one day's exposure measurement is used to draw conclusions regarding compliance on unmeasured days.

GEOMETRIC STANDARD DEVIATION

The parameter often used to express either the intraday or interday environmental variability is the *geometric standard deviation* (GSD). A GSD of 1.0 represents absolutely no variability in the environment. GSDs of 2.0 and above represent relatively high variability.

The shape of lognormal distributions with low variabilities, such as those with GSDs less than about 1.4, roughly approximate normal distribution shapes. For this range of GSDs, there is a rough equivalence between the GSD and CV as follows:

GSD	*Approximate CV*
1.40	35 percent
1.30	27 percent
1.20	18 percent
1.10	9.6 percent
1.05	4.9 percent

COMMON LOGARITHMS

N	0	1	2	3	4	5	6	7	8	9
0	....	0000	3010	4771	6021	6990	7782	8451	9031	9542
1	0000	0414	0792	1139	1461	1761	2041	2304	2553	2788
2	3010	3222	3424	3617	3802	3979	4150	4314	4472	4624
3	4771	4914	5051	5185	5315	5441	5563	5682	5798	5911
4	6021	6128	6232	6335	6435	6532	6628	6721	6812	6902
5	6990	7076	7160	7243	7324	7404	7482	7559	7634	7709
6	7782	7853	7924	7993	8062	8129	8195	8261	8325	8388
7	8451	8513	8573	8633	8692	8751	8808	8865	8921	8976
8	9031	9085	9138	9191	9243	9294	9345	9395	9445	9494
9	9542	9590	9638	9685	9731	9777	9823	9868	9912	9956
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
N	0	1	2	3	4	5	6	7	8	9

N	0	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996
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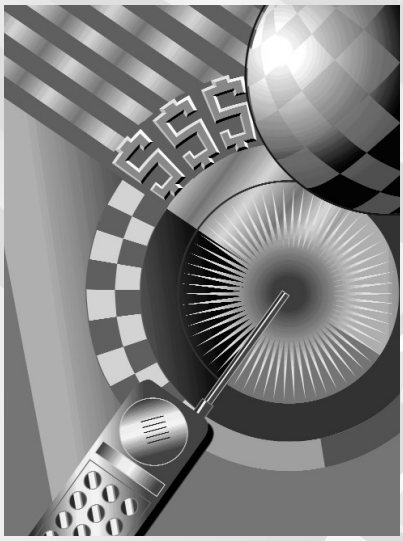
N	0	1	2	3	4	5	6	7	8	9



GLOSSARY

Appendix E

Appendix

E

Glossary

compiled by Michael Horowitz, CIH

Every industry has its own terminology. The health and safety professional must be aware of the precise meanings of certain words commonly used in industrial hygiene, occupational health, and chemistry to communicate effectively with other professionals in these areas.

A fume respirator, for instance, is worthless as protection against gases or vapors. Too often, these terms are used interchangeably; each term has a definite meaning and describes a certain state of matter that can be achieved only by certain physical changes to the given substance.

This glossary defines words and terms, some of which are peculiar to a single industry and others common to many industries. Terms were taken or adapted from the latest editions of The Chemical Industry Facts Book, *published by the Manufacturing Chemists Association, Washington, DC;* Occupational Diseases and Industrial Medicine, *by RT Johnstone and SE Miller, published by WB Saunders, Philadelphia;* Guide for Industrial Audiometric Technicians, *published by the Safety and Health Services, Employers Insurance of Wausau, WI; American National Standards S1.1:* Acoustical Terminology *and Z88.2:* Respiratory Protection; 101 Atomic Terms and What They Mean, *by the Esso Research and Engineering Company, Linden, NJ;* Paramedical Dictionary, *by JE Schmidt, published by Charles C. Thomas, Springfield, IL;* The Condensed Chemical Dictionary, *published by Van Nostrand Reinhold Publishing, New York;* Stedman's Medical Dictionary, *26th ed., published by W. B. Saunders Company, Philadelphia; and* Dictionary of Scientific and Technical Terms, *4th ed., edited by S Parker, published by McGraw-Hill.*

A

A-, an- (prefix)**.** Absent, lacking, deficient, without. Anemia: deficient in blood.

AAOHN. American Association of Occupational Health Nurses.

ABIH. American Board of Industrial Hygiene.

Abrasive blasting. A process for cleaning surfaces by means of such materials as sand, alumina, or steel grit in a stream of high-pressure air.

Absorption. In air sampling, the capture of a gas or vapor accomplished by passing an airstream containing the gas or vapor through a liquid.

Absorption coefficient. See Sound absorption coefficient.

AC. See Alternating current.

Accelerator. A device for imparting very high velocity to charged particles such as electrons or protons. Also, a chemical additive that increases the speed of a chemical reaction.

Acclimation. The process of becoming accustomed to new conditions (such as heat).

Accommodation. The ability of the eye to adjust focus for various distances.

Accuracy (instrument). Often used incorrectly as precision (see Precision). Accuracy is the agreement of a reading or observation obtained from an instrument or a technique with the true value.

ACGIH. American Conference of Governmental Industrial Hygienists. An association whose membership is open to *anyone* who is engaged in the practice of industrial hygiene or occupational and environmental health and safety.

Acid. A proton donor.

Acid pickling. A bath treatment to remove scale and other impurities from metal surfaces before plating or other surface treatment. Sulfuric acid is commonly used.

Acne. See Oil dermatitis.

Acoustic, acoustical. Containing, producing, arising from, actuated by, related to, or associated with sound.

Acoustic trauma. Hearing loss caused by sudden loud noise in one ear or by a sudden blow to the head. In most cases, hearing loss is temporary, although there may be some permanent loss.

Acro- (prefix)**.** Topmost; outer end. An extremity of the body. Acro-osteolysis is degeneration of the terminal or distal end of bone tissue.

Acrylic. A family of synthetic resins made by polymerizing esters of acrylic acids.

Action level. A term used by OSHA and NIOSH (see entries) to express the level of toxicant that requires medical surveillance, usually one half of the permissible exposure limit.

Activated charcoal. Charcoal is an amorphous form of carbon formed by burning wood, nutshells, animal bones, and other carbonaceous materials. Charcoal becomes activated by heating it with steam to 800–900 C. During this treatment, an aporous, submicroscopic internal structure is formed that gives it an extensive internal surface area. Activated charcoal is commonly used as a gas or vapor adsorbent in air-purifying respirators and as a solid sorbent in air sampling.

Activation. Making a substance artificially radioactive in an accelerator or by bombarding it with protons or neutrons in a reactor.

Activity. Often used as a shortened form of radioactivity; refers to the radiating power of a radioactive substance. Activity may be given in terms of atoms disintegrating per second.

Acuity. This sense pertains to the sensitivity of receptors used in hearing or vision.

Acute. Health effects that show up a short length of time after exposure. An acute exposure runs a comparatively short course.

ADA. Americans with Disabilities Act: a 1991 federal law prohibiting discrimination against people with disabilities in most public activities, including the workplace.

Additives. An inclusive name for a wide range of chemical substances that are added in low percentage to stabilize certain end products, such as antioxidants in rubber.

Aden- (prefix)**.** Pertaining to a gland. Adenoma is a tumor of gland-like tissue.

Adenoma. An epithelial tumor, usually benign, with a gland-like structure (the cells lining gland-like depressions or cavities in the stroma).

Adhesion. The ability of one substance to stick to another. There are two types of adhesion: mechanical, which depends on the penetration of the surface, and molecular or polar adhesion, in which adhesion to a smooth surface is obtained because of polar groups such as carboxyl groups.

Administrative controls. Methods of controlling employee exposures by job rotation, work assignment, time periods away from the hazard, or training in specific work practices designed to reduce the exposure.

Adsorption. The condensation of gases, liquids, or dissolved substances on the surfaces of solids.

AEC. Atomic Energy Commission. Now called Nuclear Regulatory Commission in the U.S. Department of Energy.

Aerobe. Microorganisms that require the presence of oxygen.

Aerodynamic equivalent diameter. In the consideration of particulates the diameter of a theoretical unit density sphere having the same settling velocity as a particle of a given shape and density. Also termed *equivalent aerodynamic diameter (EAD)*.

Aerodynamic forces. The forces exerted on a particle in suspension by either the movement of air or gases around the particle or the resistance of the gas or air to movement of the particle through the medium.

Aerosols. Liquid droplets or solid particles dispersed in air that are of fine enough particle size (0.01–100 μm) to remain so dispersed for a period of time.

Agglomeration. Implies consolidation of solid particles into larger shapes by means of agitation alone, that is, without application of mechanical pressure in molds, between rolls, or through dies. Industrial agglomeration is usually implemented in balling devices such as rotating discs, drums, or cones, but it can occur in a simple mixer. Agglomeration has also been used to describe the entire field of particulate consolidation.

AIDS. Acquired Immunodeficiency Syndrome.

AIHA. American Industrial Hygiene Association.

Air. The mixture of gases that surrounds the earth; its major components are as follows: 78.08 percent nitrogen, 20.95 percent oxygen, 0.03 percent carbon dioxide, and 0.93 percent argon. Water vapor (humidity) varies. See Standard air.

Air bone gap. The difference in decibels between the hearing levels for a particular frequency as determined by air conduction and bone conduction.

Airborne microorganisms. Biologically active contaminants suspended in air either as free-floating particles surrounded by a film or organic or inorganic material, or attached to the surface of other suspended particulates.

Air cleaner. A device designed to remove atmospheric airborne impurities, such as dusts, gases, vapors, fumes, and smokes.

Air conditioning. The process of treating air to control its temperature, humidity, cleanliness, and distribution to meet requirements of the conditioned space.

Air conduction. The process by which sound is conducted to the inner ear through air in the outer ear canal.

Air filter. An air-cleaning device to remove light particulate matter from normal atmospheric air.

Air hammer. A percussion-type pneumatic tool fitted with a handle at one end of the shank and a tool chuck at the other, into which a variety of tools may be inserted.

Air horsepower. The theoretical horsepower required to drive a fan if there are no losses in the fan, that is, if it is 100 percent efficient.

Air monitoring. The sampling for and measuring of pollutants in the atmosphere.

Air mover. Any device that is capable of causing air to be moved from one space to another. Such devices are generally used to exhaust, force, or draw gases through specific assemblies.

Air-purifying respirator. Respirators that use filters or sorbents to remove harmful substances from the air.

Air quality criteria. The amounts of pollution and lengths of exposure at which specific adverse effects to health and welfare take place.

Air-regulating valve. An adjustable valve used to regulate airflow to the facepiece, helmet, or hood of an air-line respirator.

Air, standard. See Standard air.

Air-supplied respirator. Respirator that provides a supply of breathable air from a clean source outside of the contaminated work area.

Albumin. A protein material found in animal and vegetable fluids, characterized by being soluble in water.

Albuminuria. The presence of albumin or other protein substance, such as serum globulin, in the urine.

-algia (suffix)**.** Pain. A prefix such as *neur-* tells where the pain is (*neuralgia*, for example).

Algorithm. A precisely stated procedure or set of instructions that can be applied stepwise to solve a problem.

Aliphatic. (Derived from the Greek word for *oil.*) Pertaining to an open-chain carbon compound. Usually applied to petroleum products derived from a paraffin base and having a straight or branched chain, saturated or unsaturated molecular structure. Substances such as methane and ethane, are typical aliphatic hydrocarbons. See Aromatic.

Alkali. A compound that has the ability to neutralize an acid and form a salt. Sodium hydroxide, known as caustic soda or lye, is an example. Used in soap manufacture and many other applications. Turns litmus paper blue. See Base.

Alkaline earths. Usually considered to be the oxides of alkaline earth metals: barium, calcium, strontium, beryllium, and radium. Some authorities also include magnesium oxide.

Alkyd. A synthetic resin that is the condensed product of a polybasic acid such as phthalic, a polyhydric alcohol such as glycerin, and an oil fatty acid.

Alkylation. The process of introducing one or more alkyl radicals by addition or substitution into an organic compound.

Allergy. An abnormal response of a hypersensitive person to chemical or physical stimuli. Allergic manifestations of major importance occur in about 10 percent of the population.

Alloy. A mixture of metals (and sometimes a nonmetal), as in brass.

Alpha-emitter. A radioactive substance that gives off alpha particles.

Alpha-particle (alpha-ray, alpha-radiation). A small, positively charged particle made up of two neutrons and two protons and of very high velocity, thrown off by many radioactive materials, including uranium and radium.

Alternating current (AC). Electric current that reverses direction. Ordinary house current in the United States reverses direction 60 times per second.

Aluminosis. A form of pneumoconiosis due to the presence of aluminum-bearing dust in the lungs, especially that of alum, bauxite, or clay.

Alveoli. Tiny air sacs of the lungs, formed at the ends of bronchioles; through the thin walls of the alveoli, the blood takes in oxygen and gives up carbon dioxide in respiration.

Alveolus. A general term used in anatomical nomenclature to designate a small sac-like dilation.

Amalgamation. The process of alloying metals with mercury. This is one process used in extracting gold and silver from their ores.

Ambient noise. The all-encompassing noise associated with a given environment; usually a composite of sounds from many sources.

Amorphous. Noncrystalline.

Anaerobe. A microorganism that grows without oxygen. Facultative anaerobes are able to grow with or without oxygen; obligate anaerobes grow only in the absence of oxygen.

Anaerobic bacteria. Any bacteria that can survive in a partial or complete absence of air.

Anaphylaxis. Hypersensitivity resulting from sensitization following prior contact with a chemical or protein.

Andro- (prefix)**.** Man, male. An androgen is an agent that produces masculinizing effects.

Anechoic room (free-field room). One whose boundaries effectively absorb all the sound incident therein, thereby affording essentially free-field conditions.

Anemia. Deficiency in the hemoglobin and erythrocyte content of the blood. Term refers to a number of pathological states that may be attributed to a large variety of causes and appear in many different forms.

Anemometer. A device to measure air speed.

Anesthesia. Loss of sensation; in particular, the temporary loss of feeling induced by certain chemical agents.

Angi-, angio- (prefix)**.** Blood or lymph vessel. Angiitis is the inflammation of a blood vessel.

Angle of abduction. Angle between the longitudinal axis of a limb and a sagittal plane.

Angstrom (Å). Unit of measure of wavelength equal to 1010 m or 0.1 nm.

Anneal. To treat by heat with subsequent cooling for drawing the temper of metals, that is, to soften and render them less brittle. See Temper.

Anode. The positive electrode.

Anorexia. Lack or loss of the appetite for food.

ANSI. American National Standards Institute: a voluntary membership organization (run with private funding) that develops consensus standards nationally for a wide variety of devices and procedures.

Antagonist. A muscle opposing the action of another muscle. An active antagonist is essential for control and stability of action by a prime mover.

Antagonistic interaction. Interaction of two chemicals in which the resultant toxic effect is lower than the chemicals' individual actions.

Anthracosilicosis. A complex form of pneumoconiosis; a chronic disease caused by breathing air containing dust that has free silica as one of its components and that is generated in the various processes in mining and preparing anthracite (hard) coal, and, to a lesser degree, bituminous coal.

Anthracosis. A disease of the lungs caused by prolonged inhalation of dust that contains particles of carbon and coal.

Anthrax. A highly virulent bacterial infection picked up from infected animals and animal products.

Anthropometry. The part of anthropology having to do with measurement of the human body to determine differences in individuals or groups of individuals.

Anti- (prefix)**.** Against. An antibiotic is "against life" in the case of a drug—against the life of disease-causing germs.

Antibiotic. A substance produced by a microorganism that in dilute solutions kills other organisms, or retards or completely represses their growth, normally in doses that do not harm higher orders of life.

Antibody. Any of the body globulins that combine specifically with antigens to neutralize toxins, agglutinate bacteria or cells, and precipitate soluble antigens. It is found naturally in the body or produced by the body in response to the introduction into its tissues of a foreign substance.

Antigen. A substance that when introduced into the body stimulates antibody production.

Antioxidant. A compound that retards deterioration by oxidation. Antioxidants for human food and animal feeds, sometimes referred to as freshness preservers, retard rancidity of fats and lessen loss of fat-soluble vitamins (A, D, E, K). Antioxidants also are added to rubber, motor lubricants, and other materials to inhibit deterioration.

Antiparticle. A particle that interacts with its counterpart of the same mass but opposite electric charge and magnetic properties (e.g., proton and antiproton), with complete annihilation of both and production of an equivalent amount of radiation energy. The positron and its antiparticle, the electron, annihilate each other upon interaction and produce gamma-rays.

Antiseptic. A substance that prevents or inhibits the growth of microorganisms; a substance used to kill microorganisms on animate surfaces, such as skin.

Aplastic anemia. A condition in which the bone marrow fails to produce an adequate number of red blood corpuscles.

Approved. Tested and listed as satisfactory by an authority having jurisdiction, such as U.S. Department of HHS, NIOSH-MSHA; or U.S. Department of Agriculture.

Aqueous humor. Fluid in the anterior chamber of the eye (between the cornea and the lens).

Arc welding. A form of electrical welding using either uncoated or coated rods.

Arc-welding electrode. A component of the welding circuit through which current is conducted between the electrode holder and the arc.

Area monitoring. Collection of and later analysis of airborne contaminants in a given work environment. As the sampling pump and collection media are not attached to a worker, the concentrations found represent average concentrations in that area but may not be representative of the actual exposure of the worker. See personal monitoring.

Argyria. A slate-gray or bluish discoloration of the skin and deep tissues caused by the deposit of insoluble albuminate of silver, occurring after the medicinal administration for a long period of a soluble silver salt; formerly fairly common after the use of insufflations of silver-containing materials into the nose and sinuses. Also seen with occupational exposure to silver-containing chemicals.

Aromatic. Applied to a group of hydrocarbons and their derivatives characterized by the presence of the benzene nucleus (molecular ring structure). See Aliphatic.

Arthr- (prefix)**.** Joint. Arthropathy is a disease affecting a joint.

Artificial abrasive. Materials such as carborundum or emery substituted for natural abrasive such as sandstone.

Artificial radioactivity. That produced by bombardment of a target element with nuclear particles. Iodine-131 is an artificially produced radioactive substance.

Asbestos. A hydrated magnesium silicate in fibrous form.

Asbestosis. A disease of the lungs caused by inhalation of fine airborne asbestos fibers.

Asepsis. The state of being clean and free of microorganisms.

Aseptic technique. A procedure or operation that prevents the introduction of septic material.

ASHRAE. American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Aspect ratio. Length to width ratio.

Asphyxia. Suffocation from lack of oxygen. Chemical asphyxia is produced by a substance such as carbon monoxide that combines with hemoglobin to reduce the blood's capacity to transport oxygen. Simple asphyxia is the result of exposure to a substance, such as methane, that displaces oxygen.

Asphyxiant. A gas whose primary or most acute health effect is asphyxiation. There are two classes of asphyxiant: Simple asphyxiants, such as nitrogen or methane, which act by replacing oxygen; and chemical asphyxiants, such as carbon monoxide, which cause asphyxiation by preventing oxygen uptake at the cellular level.

Assigned Protection Factor (APF). The level of respiratory protection expected from a respirator that is properly functioning, has been properly fitted, and is worn by a worker trained in its use. APFs can be used to help provide an estimate of the maximum concentrations of a contaminant in which a particular respirator can be used.

Asthma. Constriction of the bronchial tubes in response to irritation, allergy, or other stimulus.

Astigmatism. A type of blurry vision caused by irregular curvature of the cornea.

Ataxia. Lack of muscular coordination caused by any of several nervous system diseases.

Atmospheric pressure. The pressure exerted in all directions by the atmosphere. At sea level, mean atmospheric pressure is 29.92 in. Hg, 14.7 psi, or 407 in. wg.

Atmospheric tank. A storage tank designed to operate at pressures from atmospheric through 0.5 psig (3.5 kPa).

Atom. All materials are made of atoms. The elements, such as iron, lead, and sulfur, differ from each other because their atomic structures are different. The word *atom* comes from the Greek word meaning indivisible. We now know it can be split and consists of an inner core (nucleus) surrounded by electrons that rotate around the nucleus. As a chemical unit, it remains unchanged during any chemical reaction, yet may undergo nuclear transmutations to other atoms, as in atomic fission.

Atom smasher. Accelerator that speeds up atomic and subatomic particles so that they can be used as projectiles to literally blast apart the nuclei of other atoms.

Atomic energy. Energy released in nuclear reactions. Of particular interest is the energy released when a neutron splits an atom's nucleus into smaller pieces (fission) or when two nuclei are joined together under millions of degrees of heat (fusion). *Atomic energy* is a popular misnomer; it is more correctly called nuclear energy.

Atomic hydrogen welding. A shielded gas-electric welding process using hydrogen as the reducing atmosphere.

Atomic number. The number of protons found in the nucleus of an atom. All elements have different atomic numbers. The atomic number of hydrogen is 1, that of oxygen 8, iron 26, lead 82, uranium 92. The atomic number is also called charge number and is usually denoted by Z.

Atomic power. The name given to the production of thermal power in a nuclear reactor or power facility.

Atomic waste. The radioactive ash produced by the splitting of uranium fuel, as in a nuclear reactor. It may include products made radioactive in such a device.

Atomic weight. The atomic weight is approximately the sum of the number of protons and neutrons found in the nucleus of an atom. This sum is also called mass number. The atomic weight of oxygen is approximately 16, with most oxygen atoms containing 8 neutrons and 8 protons. Aluminum is 27; it contains 14 neutrons and 13 protons.

Atrophy. Arrested development or wasting away of cells and tissue.

Attenuate. To reduce in amount. Usually refers to noise or ionizing radiation.

Attenuation. The reduction of intensity at a designated first location as compared with intensity at a second location, which is farther from the source.

Attenuation block. A block or stack, having dimensions 20 cm by 20 cm by 3.8 cm, of Type 1100 aluminum alloy or aluminum alloy having equivalent attenuation.

Audible range. The frequency range across which normal ears hear: approximately 20 Hz to 20,000 Hz. Above the range of 20,000 Hz, the term ultrasonic is used. Below 20 Hz, the term subsonic is used.

Audible sound. Sound containing frequency components lying between 20 and 20,000 Hz.

Audiogram. A record of hearing loss or hearing level measured at several different frequencies—usually 500 to 6,000 Hz. The audiogram may be presented graphically or numerically. Hearing level is shown as a function of frequency.

Audiologist. A person with graduate training in the specialized problems of hearing and deafness.

Audiometer. A signal generator or instrument for measuring objectively the sensitivity of hearing. Pure-tone audiometers are standard instruments for industrial use for audiometric testing.

Audiometric technician. A person who is trained and qualified to administer audiometric examinations.

Audiometric zero. The threshold of hearing: 0.0002 microbars of sound pressure. See Decibel.

Auditory. Pertaining to or involving the sense or organs of hearing.

Auricle. Part of the ear that projects from the head; medically, the pinna. Also, one of the two upper chambers of the heart.

Autoclave. An apparatus using pressurized steam for sterilization.

Autoignition temperature. The lowest temperature at which a flammable gas-air or vapor-air mixture ignites from its own heat source or a contacted heated surface without necessity of spark or flame. Vapors and gases spontaneously ignite at a lower temperature in oxygen than in air, and their autoignition temperature may be influenced by the presence of catalytic substances.

Avogadro's number. The number of molecules in a mole of any substance; it equals 6.02217×10^3. At 0 C and 29.92 in. Hg, 1 mole of any gas occupies 22.414 liters of volume.

Axial-flow fan. A propeller-type fan useful for moving large volumes of air against little resistance.

Axis of rotation. The true line about which angular motion takes place at any instant. Not necessarily identical with anatomical axis of symmetry of a limb, nor necessarily fixed. Thus, the forearm rotates about an axis that extends obliquely from the lateral side of the elbow to a point between the little finger and ring finger. The elbow joint has a fixed axis maintained by circular joint surfaces, but the knee has a moving axis as its cam-shaped surfaces articulate. Axis of rotation of tools should be aligned with true limb axis of rotation. System of rotation of tools should be aligned with true limb axis of rotation. Systems of predetermined motion times often specify such an axis incorrectly.

Axis of thrust. The line along which thrust can be transmitted safely. In the forearm, it coincides with the longitudinal axis of the radius. Tools should be designed to align with this axis.

B

Babbitt. An alloy of tin, antimony, copper, and lead used as a bearing metal.

Babbitting. The process of applying babbitt to a bearing.

Bacillus. A rod-shaped bacterium.

Background radiation. The radiation coming from sources other than the radioactive material to be measured. This background is primarily because of cosmic rays that constantly bombard the earth from outer space.

Background noise. Noise coming from sources other than the particular noise source being monitored.

Bacteria. Microscopic organisms living in soil, water, organic matter, or the bodies of plants and animals characterized by lack of a distinct nucleus and lack of ability to photosynthesize. Singular: Bacterium.

Bactericide. Any agent that destroys bacteria.

Bacteriophage. Viruses that infect bacteria and lyse the bacterial cell.

Bacteriostat. An agent that stops the growth and multiplication of bacteria but does not necessarily kill them. Usually growth resumes when the bacteriostat is removed.

Bag house. Many different trade meanings. Commonly connotes the housing containing bag filters for recovery of fumes of arsenic, lead, sulfur, and others from the flues of smelters.

Bagasse. Sugar cane pulp residues.

Bagassosis. Respiratory disorder believed to be caused by breathing fungi found in bagasse.

Balancing by dampers. Method for designing local exhaust system ducts using adjustable dampers to distribute airflow after installation.

Balancing by static pressure. Method for designing local exhaust system ducts by selecting the duct diameters that generate static pressure to distribute airflow without dampers.

Ball mill. A grinding device using balls usually made of steel or stone in a revolving container.

Banbury mixer. A mixing machine that permits control over the temperature of the batch; commonly used in the rubber industry.

Band-pass filter. A wave filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency.

Band-pressure level. Band-pressure level of a sound for a specified frequency band is the sound-pressure level for the sound contained within the restricted band. The reference pressure must be specified.

Bandwidth. When applied to a band-pass filter, bandwidth is determined by the interval of transmitted waves between the low and high cutoff frequencies.

Baritosis. An inert pneumoconiosis produced by the inhalation of insoluble barium compounds.

Barotrauma. An injury to the ear caused by a sudden alteration in barometric (atmospheric) pressure; aerotitis.

Basal metabolism. A measure of the amount of energy required by the body at rest.

Base. A compound that reacts with an acid to form a salt; another term for alkali. It turns litmus paper blue.

Basilar. Of, relating to, or situated at the base.

Bauxite. Impure mixture of aluminum oxides and hydroxides; the principal source of aluminum.

Bauxite pneumoconiosis. Shaver's disease. Found in workers exposed to fumes containing aluminum oxide and minute silica particles arising from smelting bauxite in the manufacture of corundum.

Beam axis. A line from the source through the centers of the x-ray fields.

Beam divergence. Angle of beam spread measured in mrad (1 mrad = 3.4 min of arc).

Beam-limiting device. A device that provides a means to restrict the dimensions of an x-ray field.

Beat elbow. Bursitis of the elbow; occurs from use of heavy vibrating tools.

Beat knee. Bursitis of the knee joints caused by friction or vibration; common in mining.

Becquerel (Bq). One disintegration per second; a measure of the rate of radioactive disintegration. There are 37 billion Bqs per curie.

Beehive kiln. A kiln shaped like a large beehive usually used for calcining ceramics.

BEI. See Biological exposure indices.

Bel. A unit of sound level based on a logarithmic scale.

Belding-Hatch index. (See also Heat stress index.) Estimate of the body heat stress of a standard man for various degrees of activity; also relates to sweating capacity.

Benign. Not malignant. A benign tumor is one that does not metastasize or invade tissue. Benign tumors may still be lethal because of pressure on vital organs.

Benzene, CH. A major organic intermediate and solvent derived from coal or petroleum. The simplest member of the aromatic series of hydrocarbons.

Beryl. A silicate of beryllium and aluminum.

Berylliosis. Chronic beryllium intoxication.

Beta decay. The process whereby some radioactive emitters give off a beta particle. Also called beta disintegration.

Beta particle (beta-radiation). A small electrically charged particle thrown off by many radioactive materials; identical to the electron. Beta particles emerge from radioactive material at high speeds.

Betatron. A large doughnut-shaped accelerator in which electrons (beta particles) are whirled through a changing magnetic field gaining speed with each trip and emerging with high energies. Energies of the order of 100 million electron volts have been achieved. The betatron produces artificial beta radiation.

Biceps brachii muscle. The large muscle in the front of the upper arm. Supinates the forearm.

Bicipital tuberosity. A protuberance on the medial surface of the radius to which the biceps brachii attaches.

Billet. A piece of semifinished iron or steel, nearly square in section, made by rolling and cutting an ingot.

Binder. The nonvolatile portion of a coating vehicle that is the film-forming ingredient used to bind the paint pigment particles together.

Binding energy. The energy that holds the neutrons and protons of an atomic nucleus together. Represents the difference between the mass of an atom and the sum of the masses of protons and neutrons that make up its nucleus.

Bioaerosol. Airborne particles of biological origin (living or dead) including microorganisms and their fragments, toxins, and particulate waste products from all varieties of living things.

Biohazard. An abbreviation of *biological hazard*. Organisms or products of organisms that present a risk to humans.

Biohazard area. Any area (a complete operating complex, a single facility, a room within a facility, and so on) in which work has been or is being performed with biohazardous agents or materials.

Biohazard control. Any set of equipment and procedures used to prevent or minimize the exposure of humans and their environment to biohazardous agents or materials.

Biological Exposure Indices® (BEI®). Advisory biological limit values adopted by the ACGIH for some substances. Indices are based on urine, blood, or expired air samples. A BEI may be a value for the substance itself or it may refer to a level of a metabolite. BEIs represent the value of the biological determinant that is most likely to be the value of that determinant obtained from a worker exposed at the 8-hour TLV-TWA for the substance in question.

Biological half-life. The time required to reduce the amount of an exogenous substance in the body by half.

Biological monitoring. Collection and analysis for chemical contaminants or their metabolites of expelled biological material such as blood or urine from which estimates of worker exposure to the chemical can be made.

Biological oxygen demand (BOD). Quantity of oxygen required for the biological and chemical oxidation of waterborne substances under test conditions.

Biomechanics. The study of the human body as a system operating under two sets of laws: the laws of Newtonian mechanics and the biological laws of life.

Biopsy. Careful removal of small bits of living tissue from the body for further study and examination, usually under the microscope.

Black liquor. A liquor composed of alkaline and organic matter resulting from digestion of wood pulp and cooking acid during the manufacture of paper.

Bleaching bath. Chemical solution used to bleach colors from a garment preparatory to dyeing it; a solution of chlorine or sodium hypochlorite is commonly used.

Bleph- (prefix)**.** Pertaining to the eyelid.

Blind spot. Normal defect in the visual field due to the position at which the optic nerve enters the eye.

Bloodborne pathogen program. A 1992 OSHA standard mandates exposure control plans and the use of universal precautions for places of employment where there is risk of employee exposure to blood or other potentially infectious material. Hepatitis B and HIV are the most often-discussed pathogens, but the program is not limited to these two areas.

Blood count. A count of the number of corpuscles per cubic millimeter of blood. Separate counts may be made for red and white corpuscles (blood cells).

BLS. Bureau of Labor Statistics.

Body burden. The amount of noxious material in the body at a given time.

Body burden, maximum permissible. The body burden of a radionuclide that if maintained at a constant level would produce the maximum permissible dose equivalent in the critical organ.

Boiling point. The temperature at which the vapor pressure of a liquid equals atmospheric pressure.

Bombardment. Shooting neutrons, alpha particles, and other high-energy particles at atomic nuclei, usually in an attempt to split the nucleus or to form a new element.

Bone conduction test. A special test conducted by placing an oscillator on the mastoid process to determine the nerve-carrying capacity of the cochlea and the eighth cranial (auditory) nerve.

Bone marrow. A soft tissue that constitutes the central filling of many bones and that produces blood corpuscles.

Bone-seeker. Any element or radioactive species that lodges in the bone when introduced into the body.

Brachialis muscle. Short, strong muscles originating at the lower end of the humerus and inserting into the ulna. Powerful flexor of forearm; employed when lifting.

Brady- (prefix)**.** Slow. Bradycardia is slow heartbeat.

Bradycardia. Abnormal slowness of the heartbeat, as evidenced by slowing of the pulse rate to 50 or less.

Brake horsepower. The horsepower required to drive a unit; it includes the energy losses in the unit and can be determined only by actual test. It does not include drive losses between the motor and unit.

Branch (or path) of greatest resistance. The path from a hood to the fan and exhaust stack in a ventilation system that causes the most pressure loss.

Brass. An alloy of copper and zinc that may contain a small amount of lead.

Brattice. A partition constructed in underground passageways to control ventilation in mines.

Braze. To solder with any relatively infusible alloy.

Brazing furnace. Used for heating metals to be joined by brazing. Requires a high temperature.

Breathing tube. A tube through which air or oxygen flows to the facepiece, helmet, or hood.

Breathing zone. Imaginary globe of two foot radius surrounding the head.

Breathing zone sample. An air-sample collected in the breathing zone of workers to assess their exposure to airborne contaminants.

Bremsstrahlung. Secondary x-radiation produced when a beta particle is slowed down or stopped by a high-density surface.

Briquette. Coal or ore dust pressed into oval or brick-shaped blocks.

Broach. A cutting tool for cutting non-round holes.

Bronch-, broncho- (prefix)**.** Pertaining to the air tubes of the lung.

Bronchial tubes. Branches or subdivisions of the trachea (windpipe). A bronchiole is a branch of a bronchus, which is a branch of the windpipe.

Bronchiectasis. A chronic dilation of the bronchi or bronchioles marked by fetid breath and paroxysmal coughing, with the expectoration of mucopurulent matter. It may affect the tube uniformly, or may occur in irregular pockets, or the dilated tubes may have terminal bulbous enlargements.

Bronchiole. The slenderest of the many tubes that carry air into and out of the lungs.

Bronchiolitis. See Bronchopneumonia.

Bronchitis. Inflammation of the bronchi or bronchial tubes.

Bronchoalveolitis. Bronchopneumonia.

Bronchopneumonia. A name given to an inflammation of the lungs that usually begins in the terminal bronchioles. These become clogged with a mucopurulent exudate forming consolidated patches in adjacent lobules. The disease is essentially secondary in character, following infections of the upper respiratory tract, specific infectious fevers, and debilitating diseases.

Bronzing. Act or art of imparting a bronze appearance with powders, painting, or chemical processes.

Brownian motion. The irregular movement of particles suspended in a fluid as a result of bombardment by atoms and molecules.

Brucella. A genus of short, rod-shaped to coccoid, encapsulated, gram-negative, parasitic, pathogenic bacteria.

Brucellosis. A group of diseases caused by an organism of the *Brucella* genus. Undulant fever. One source is unpasteurized milk from cows suffering from Bang's disease (infectious abortion).

Bubble chamber. A chamber containing a liquefied gas such as liquid hydrogen, under conditions such that a charged particle passing through the liquid forms bubbles that make its path visible.

Bubble tube. A device used to calibrate air-sampling pumps.

Buffer. Any substance in a fluid that tends to resist the change in pH when acid or alkali is added.

Bulk facility. That portion of a property where flammable or combustible liquids are received by tank vessel, pipeline, tank car, or tank vehicle, and are sorted or blended in bulk for the purpose of distributing such liquids.

Burn-up. The extent to which the nuclear fuel in a fuel element has been consumed by fission, as in a nuclear reactor.

Burns. Result of the application of too much heat to the skin. First degree burns show redness of the unbroken skin; second degree, skin blisters and some breaking of the skin; third degree, skin blisters and destruction of the skin and underlying tissues, which can include charring and blackening.

Burr. The thin rough edges of a machined piece of metal.

Bursa. A synovial lined sac that facilitates the motion of tendons; usually near a joint.

Bursitis. Inflammation of a bursa.

Byssinosis. Disease occurring to those who experience prolonged exposure to heavy air concentrations of cotton or flax dust.

C

Calcination. The heat treatment of solid material to bring about thermal decomposition, to lose moisture or other volatile material, or to oxidize or reduce.

Calender. An assembly of rollers for producing a desired finish on paper, rubber, artificial leather, plastic, or other sheet material.

Caulking. The process or material used to fill seams of boats, cracks in tile, etc.

Calorimeter. A device for measuring the total amount of energy absorbed from a source of electromagnetic radiation.

Cancer. A cellular tumor the natural course of which is fatal and usually associated with formation of secondary tumors.

Capitulum of humerus. A smooth hemispherical protuberance at the distal end of the humerus articulating with the head of the radius. Irritation caused by pressure between the capitulum and head of the radius may be a cause of tennis elbow.

Capture velocity. Air velocity at any point in front of the hood necessary to overcome opposing air currents and to capture the contaminated air by causing it to flow into the exhaust hood.

Carbohydrate. An abundant class of organic compounds, serving as food reserves or structural elements for plants and animals. Compounded primarily of carbon, hydrogen, and oxygen, they constitute about two thirds of the average daily adult caloric intake. Sugar, starches, and plant components (cellulose) are all carbohydrates.

Carbon black. Essentially a pure carbon, best known as common soot. Commercial carbon black is produced by making soot under controlled conditions. It is sometimes called furnace black, acetylene black, or thermal black.

Carbon monoxide. A colorless, odorless, toxic gas produced by any process that involves the incomplete combustion of carbon-containing substances. It is emitted through the exhaust of gasoline-powered vehicles.

Carbonizing. The immersion in sulfuric acid of semiprocessed felt to remove any vegetable matter present.

Carborundum. A trade name for silicon carbide, widely used as an abrasive.

Carboy. A large glass bottle, usually protected by a crate.

Carboxyhemoglobin. The reversible combination of carbon monoxide with hemoglobin.

Carcinogenic. Cancer-producing.

Carcinoma. Malignant tumors derived from epithelial tissues, that is, the outer skin, the membranes lining the body cavities, and certain glands.

Cardi-, cardio- (prefix)**.** Denoting the heart.

Cardiac. (1) Pertaining to the heart; (2) a cordial or restorative medicine; (3) a person with heart disorder.

Carding. The process of combing or untangling wool, cotton, and so on.

Carding machine. A textile industry machine that prepares wool, cotton, or other fibers for spinning.

Cardiovascular. Relating to the heart and to the blood vessels or circulation.

Carp- (prefix)**.** The wrist.

Carpal tunnel. A passage in the wrist through which the median nerve and many tendons pass to the hand from the forearm.

Carpal tunnel syndrome. A common affliction caused by compression of the median nerve in the carpal tunnel. Often associated with tingling, pain, or numbness in the thumb and first three fingers—may be job-related.

Carrier. A person in apparent good health who harbors a pathogenic microorganism.

Carrier gas. A mixture of gases that contains and moves a contaminant material. Components of the carrier gas are not considered to cause air pollution or react with the contaminant material.

CAS number. Identifies a particular chemical by the Chemical Abstract Service, a service of the American Chemical Society that indexes and compiles abstracts of worldwide chemical literature called Chemical Abstracts.

Case-hardening. A process of surface-hardening metals by raising the carbon or nitrogen content of the outer surface.

Cask (or coffin). A thick-walled container (usually lead) used for transporting radioactive materials.

Casting. Pouring a molten material into a mold and permitting it to solidify to a desired shape.

Catalyst. A substance that changes the speed of a chemical reaction but that undergoes no permanent change itself. In respirator use, a substance that converts a toxic gas (or vapor) into a less toxic gas (or vapor). Usually catalysts greatly increase the reaction rate, as in conversion of petroleum to gasoline by cracking. In paint manufacture, catalysts, which hasten film-forming, sometimes become part of the final product. In most uses, however, they do not, and can often be used over again.

Cataract. Opacity in the lens of the eye that may obscure vision.

Cathode. The negative electrode.

Catwalk. A narrow suspended footway usually used for inspection or maintenance purposes.

Caustic. Something that strongly irritates, burns, corrodes, or destroys living tissue. See Alkali.

Ceiling limit (C). An airborne concentration of a toxic substance in the work environment that should never be exceeded.

Cell. A structural unit of which tissues are made. There are many types: nerve cells, muscle cells, blood cells, connective tissues cells, fat cells, and others. Each has a special form to serve a particular function.

Cellulose. A carbohydrate that makes up the structural material of vegetable tissues and fibers. Its purest forms are chemical cotton and chemical pulp; it is the basis of rayon, acetate, and cellophane.

Celsius (C). The Celsius temperature scale is a designation of the scale previously known as the centigrade scale.

-cele (suffix)**.** Swelling or herniation of a part, as in *rectocele* (prolapse of the rectum).

Cement, portland. Portland cement commonly consists of hydraulic calcium silicates to which the addition of certain materials in limited amounts is permitted. Ordinarily, the

mixture consists of calcareous materials such as limestone, chalk, shells, marl, clay, shale, blast furnace slag, and so on. In some specifications, iron ore and limestone are added. The mixture is fused by calcining at temperatures usually up to 1,500 C.

Centrifugal fan. Wheel-type fan useful where static pressure is medium to high.

Centrifuge. An apparatus that uses centrifugal force to separate or remove particulate matter suspended in a liquid.

Cephal- (prefix)**.** Pertaining to the head. *Encephal-*, "within the head," pertains to the brain.

Ceramic. A term applied to pottery, brick, and tile products molded from clay and subsequently calcined.

Cerumen. Earwax.

Cervi- (prefix)**.** Neck.

CFR. See *Code of Federal Regulations.*

Chain reaction. When a fissionable nucleus is split by a neutron it releases energy and one or more neutrons. These neutrons split other fissionable nuclei releasing more energy and more neutrons, making the reaction self-sustaining for as long as there are enough fissionable nuclei present.

Charged particles. A particle that possesses at least a unit electrical charge and that does not disintegrate upon a loss of charge. Charged particles are characterized by particle size, number, and sign of unit charges and mobility. See also Ion.

Chelating agent or chelate. (Derived from Greek word *kelos* for claw.) Any compound that inactivates a metallic ion with the formation of an inner ring structure in the molecule, the metal ion becoming a member of the ring. The original ion, thus chelated, is effectively out of action.

Chemical cartridge. The type of absorption unit used with a respirator for removal of low concentrations of specific vapors and gases.

Chemical engineering. That branch of engineering concerned with the development and application of manufacturing processes in which chemical or certain physical changes of materials are involved. These processes usually may be resolved into a coordinated series of unit physical operations and unit chemical processes. The work of the chemical engineer is concerned primarily with the design, construction, and operation of equipment and facilities in which these unit operations and processes are applied.

Chemical burns. Generally similar to those caused by heat. After emergency first aid, their treatment is the same as that for thermal burns. In certain instances, such as with hydrofluoric acid, special treatment is required.

Chemical hygiene plan. Required by OSHA to protect laboratory employees from hazardous chemicals.

Chemical reaction. A change in the arrangement of atoms or molecules to yield substances of different composition and properties. Common types of reactions are combination, decomposition, double decomposition, replacement, and double replacement.

Chemotherapy. Use of chemicals of particular molecular structure in the treatment of specific disorders on the assumption that known structures exhibit an affinity for certain parts of malignant cells or infectious organisms, and thereby tend to destroy or inactivate them.

Chert. A microcrystalline form of silica. An impure form of flint used in abrasives.

Cheyne-Stokes respiration. The peculiar kind of breathing usually observed with unconscious or sleeping individuals who seem to stop breathing altogether for 540 seconds, then start up again with gradually increasing intensity, stop breathing once more, and then repeat the performance. Common in healthy infants.

Chloracne. Caused by chlorinated naphthalenes and polyphenyls acting on sebaceous glands.

Chol-, chole- (prefix)**.** Relating to bile. Cholesterol is a substance found in bile.

Chon-, chondro- (prefix)**.** Cartilage.

Chromatograph. An instrument that separates and analyzes mixtures of chemical substances.

Chromosome. Important rod-shaped constituent of all cells. Chromosomes contain the genes and are made up of deoxyribonucleic acids (DNA).

Chronic. Persistent, prolonged, repeated.

Cilia. Tiny hairlike whips in the bronchi and other respiratory passages that aid in the removal of dust trapped on these moist surfaces.

Ciliary. Pertaining to the cilium (pl. cilia), a minute vibratile hairlike process attached to the free surface of a cell.

Clays. A great variety of aluminum-silicate-bearing rocks that are plastic when wet and hard when dry. Used in pottery, stoneware, tile, bricks, cements, fillers, and abrasives. Kaolin is one type of clay. Some clay deposits may include appreciable quartz. Commercial grades of clays may contain up to 20 percent quartz.

Clostridium botulinum. Human pathogenic bacteria that produce an exotoxin, botulin, which causes botulism.

Cloud chamber. A glass-domed chamber filled with moist vapor. When certain types of atomic particles pass through the chamber they leave a cloud-like track much like the vapor trail of a jet plane. This permits scientists to see these particles and study their motion. The cloud chamber and bubble chamber serve the same purpose.

CNS. Central nervous system.

Coagulase. An enzyme produced by pathogenic staphylococci; causes coagulation of blood plasma.

Coagulation. Formation of a clot or gelatinous mass.

Coalesce. To unite into a whole; to fuse; to grow together.

Coated welding rods. The coatings of welding rods vary. For the welding of iron and most steel, the rods contain manganese, titanium, and a silicate.

Coccidiomycosis. A fungal disease (also known as valley fever or San Joaquin Valley fever) that can affect agricultural, horticultural, construction, and any workers who disturb soil containing spores. Although most often a respiratory disease, in rare cases it can be systemic and fatal. It is trans-

mitted by inhalation of dust containing spores of *Coccidioides immitis.*

Coccus. A spherical bacterium. Plural: cocci.

Cochlea. The auditory part of the internal ear, shaped like a snail shell. It contains the basilar membrane on which the end organs of the auditory nerve are distributed.

Code of Federal Regulations. The rules promulgated under U.S. law, published in the *Federal Register*, and actually enforced at the end of a calendar year are incorporated in this code (CFR).

Coefficient of discharge. A factor used in figuring flow through an orifice. The coefficient takes into account the facts that a fluid flowing through an orifice contracts to a cross-sectional area that is smaller than that of the orifice, and there is some dissipation of energy caused by turbulence.

Coefficient of entry. The actual rate of flow caused by a given hood static pressure compared to the theoretical flow that would result if the static pressure could be converted to velocity pressure with 100 percent efficiency; it is the ratio of actual to theoretical flow.

Coefficient of variation. The ratio of the standard deviation to the mean value of a population of observations.

Coffin. A thick-walled container (usually lead) used for transporting radioactive materials.

Cohesion. Molecular forces of attraction between particles of like compositions.

Colic. A severe cramping, gripping pain in or around the abdomen.

Collagen. An albuminoid, the main supportive protein of skin, tendon, bone, cartilage, and connective tissue.

Collection efficiency. The percentage of a specific substance removed and retained from air by an air cleaning or sampling device. A measure of the cleaner or sampler performance.

Collimated beam. A beam of light with parallel waves.

Colloid. Generally a liquid mixture or suspension in which the particles of suspended liquid or solid are very finely divided. Colloids do not appreciably settle out of suspension.

Colloid mill. A machine that grinds materials into a very fine state of suspension, often simultaneously placing this suspension in a liquid.

Colorimetry (colorimetric). The term applied to all chemical analysis techniques involving reactions in which a color is developed when a particular contaminant is present in the sample and reacts with the collection medium. The resultant color intensity is measured to determine the contaminant concentration.

Coma. A level of unconsciousness from which a patient cannot be aroused.

Combustible liquids. Combustible liquids are those having a flash point at or above 100 F (37.8 C).

Comedones. Blackheads. Blackened, oily masses of dead epithelial matter clogging the openings of oil glands and hair follicles.

Comfort ventilation. Airflow intended to maintain comfort of room occupants (heat, humidity, and odor).

Comfort zone. The range of effective temperatures over which the majority of adults feels comfortable.

Communicable. A disease whose causative agent is readily transferred from one person to another.

Compaction. The consolidation of solid particles between rolls or by tamp, piston, screw, or other means of applying mechanical pressure.

Compound. A substance composed of two or more elements joined according to the laws of chemical combination. Each compound has its own characteristic properties different from those of its constituent elements.

Compressible flow. Flow of high-pressure gas or air that undergoes a pressure drop resulting in a significant reduction of its density.

Compton effect. The glancing collision of a gamma-ray with an electron. The gamma-ray gives up part of its energy to the electron.

Concentration. The amount of a given substance in a stated unit of measure. Common methods of stating concentration are percent by weight or by volume, weight per unit volume, normality, and so on.

Conchae. See Turbinates.

Condensate. The liquid resulting from the process of condensation. In sampling, the term is generally applied to the material that is removed from a gas sample by means of cooling.

Condensation. Act or process of reducing from one form to another denser form such as steam to water.

Condensoid. A dispersoid consisting of liquid or solid particles formed by the process of condensation. The dispersoid is commonly referred to as a condensation aerosol.

Conductive hearing loss. Type of hearing loss; not caused by noise exposure, but by any disorder in the middle or external ear that prevents sound from reaching the inner ear.

Confined space. Any enclosed area not designed for human occupancy that has a limited means of entry and egress and in which existing ventilation is not sufficient to ensure that the space is free of a hazardous atmosphere, oxygen deficiency, or other known or potential hazards. Examples are storage tanks, boilers, sewers, and tank cars. A permit-required confined space, as defined by the OSHA standard, is one that requires a permit process and implementation of a comprehensive confined space entry program prior to entry.

Congenital. Some problem that originates before birth.

Conjunctiva. The delicate mucous membrane that lines the eyelids and covers the exposed surface of the eyeball.

Conjunctivitis. Inflammation of the conjunctiva.

Contact dermatitis. Dermatitis caused by contact with a substance—gaseous, liquid, or solid. May be caused by primary irritation or an allergy.

Control rod. A rod (containing an element such as boron) used to control the power of a nuclear reactor. The

control rod absorbs neutrons that would normally split the fuel nuclei. Pushing the rod in reduces the release of atomic power; pulling out the rod increases it.

Controlled areas. A specified area in which exposure of personnel to radiation or radioactive material is controlled and that is under the supervision of a person who knows appropriate radiation protection practices, including pertinent regulations, and who is responsible for applying them.

Convection. The motions in fluids resulting from differences in density and the action of gravity.

Converter. A nuclear reactor that uses one kind of fuel and produces another. For example, a converter charged with uranium isotopes might consume uranium-235 and produce plutonium from uranium-238. A breeder reactor produces more atomic fuel than it consumes; a converter does not.

Coolants. Transfer agents used in a flow system to convey heat from its source.

Copolymers. Mixed polymers or heteropolymers. Products of the polymerization of two or more substances at the same time.

Core. (1) The heart of a nuclear reactor where the nuclei of the fuel fission (split) and release energy. The core is usually surrounded by a reflecting material that bounces stray neutrons back to the fuel. It is usually made up of fuel elements and a moderator. (2) A shaped, hard-baked cake of sand with suitable compounds that is placed within a mold, forming a cavity in the casting when it solidifies. (3) The vital centers of the body—heart, viscera, brain—as opposed to the shell—the limbs and integument.

Corium. The deeper skin layer containing the fine endings of the nerves and the finest divisions of the blood vessels, the capillaries. Also called the derma.

Cornea. Transparent membrane covering the anterior portion of the eye.

Corpuscle. A red or white blood cell.

Corrected effective temperature (CET). An index of thermal stress similar to the effective temperature index except that globe temperature is used instead of dry-bulb temperature.

Corrective lens. A lens ground to the wearer's individual prescription.

Corrosion. Physical change, usually deterioration or destruction, brought about through chemical or electrochemical action, as contrasted with erosion, caused by mechanical action.

Corrosive. A substance that causes visible destruction or permanent changes in human skin tissue at the site of contact.

Corundum. An impure form of aluminum oxide.

Cosmic rays. High-energy rays that bombard the earth from outer space. Some penetrate to the earth's surface and others may go deep into the ground. Although each ray is energetic, the number bombarding the planet is so small that the total energy reaching the earth is about the same as that from starlight.

Costo- (prefix)**, costal.** Pertaining to the ribs.

Cottrell precipitator. A device for dust collection using high-voltage electrodes.

Coulometry. Measurement of the number of electrons that are transferred across an electrode solution interface when a reaction in the solution is created and carried to completion. The reaction is usually caused by a contaminant in a sample gas that is drawn through or onto the surface of the solution. The number of electrons transferred in terms of coulombs is an indication of the contaminant concentrations.

Count. A click in a Geiger counter or the numerical value for the activity of a radioactive specimen.

Counter. A device for counting. See Geiger counter and Scintillation counter.

Count median size. The size of the particle in a sample of particulate matter containing equal numbers of particles larger and smaller than the stated size.

Covered electrode. A composite filler metal electrode consisting of a core of bare electrode or metal-cored electrode to which a covering (sufficient to provide a slag layer on the weld metal) has been applied. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld.

Cps. Cycles per second, now called "hertz."

Cracking. Used almost exclusively in the petroleum industry, cracking is thermal or catalytic decomposition of organic compounds, usually for the manufacture of gasoline. Petroleum constituents are also cracked for the purpose of manufacturing chemicals.

Cramps. Painful muscular contractions that may affect almost any voluntary or involuntary muscle.

Cranio- (prefix)**.** Skull. As in *craniotomy*, incision through a skull bone.

Cristobalite. A crystalline form of free silica, extremely hard and inert chemically, and very resistant to heat. Quartz in refractory bricks and amorphous silica in diatomaceous earth are altered to cristobalite when exposed to high temperatures (calcined).

Critical mass. The amount of nuclear fuel necessary to sustain a chain reaction. If too little fuel is present, too many neutrons will stray, and the reaction will die out.

Critical pressure. The pressure under which a substance may exist as a gas in equilibrium with the liquid at the critical temperature.

Critical temperature. The temperature above which a gas cannot be liquefied by pressure alone.

Crucible. A heat-resistant barrel-shaped pot used to hold metal during melting in a furnace or in other applications.

Crude petroleum. Hydrocarbon mixtures that have a flash point below 150 F (65.6 C) and that have not been processed in a refinery.

Cry-, cryo- (prefix)**.** Very cold.

Cryogenics. The field of science dealing with the behavior of matter at very low temperatures.

CTD. See Cumulative trauma disorder.

Cubic centimeter (cm^3). A volumetric measurement that is equal to one milliliter (mL). Also noted as cc.

Cubic meter (m^3). A measure of volume in the metric system.

Culture (biology)**.** A population of microorganisms or tissue cells cultivated in a medium.

Culture medium. Any substance or preparation suitable for the growth of cultures and cultivation of microorganisms. Selective medium, a medium composed of nutrients designed to allow growth of a particular type of microorganism; broth medium, a liquid medium; agar medium, solid culture medium.

Cumulative trauma disorder (CTD). A disorder of a musculoskeletal or nervous system component caused or aggravated by repeated and/or forceful movements of the same musculoskeletal systems.

Curie (Ci). A measure of the rate at which a radioactive material decays. The radioactivity of one gram of radium is a curie. It is named for Pierre and Marie Curie, pioneers in radioactivity and discoverers of the elements radium, radon, and polonium. One curie corresponds to 37 billion disintegrations per second. See also Becquerel.

Cutaneous. Pertaining to or affecting the skin.

Cuticle. The superficial scarfskin or upper strata of skin.

Cutie-pie. A portable instrument equipped with a direct-reading meter used to determine the level of ionizing radiation in an area.

Cutting fluids (oils). The cutting fluids used in industry today are usually an oil or an oil-water emulsion used to cool and lubricate a cutting tool. Cutting oils are usually light or heavy petroleum fractions.

CW laser. Continuous wave laser.

Cyan- (prefix)**.** Blue.

Cyanide (as CN). Cyanides inhibit tissue oxidation upon inhalation or ingestion and cause death.

Cyanosis. Blue appearance of the skin, especially on the face and extremities, indicating a lack of sufficient oxygen in the arterial blood.

Cyclone separator. A dust-collecting device that has the ability to separate particles by size. Typically used to collect respirable dust samples.

Cyclotron. A particle accelerator. In this atomic "merry-go-round," atomic particles are whirled around in a spiral between the ends of a huge magnet, gaining speed with each rotation in preparation for their assault on the target material.

Cyst- (prefix)**.** Pertaining to a bladder or sac, normal or abnormal, filled with gas, liquid, or semisolid material. The term appears in many words concerning the urinary bladder (*cystocele, cystitis*).

Cyto- (prefix)**.** Cell.

Cytoplasm. Cell plasma (protoplasm) that does not include the cell's nucleus.

Cytotoxin. A substance, developed in the blood serum, having a toxic effect upon cells.

D

Damage risk criterion. The suggested baseline of noise tolerance, which, if not exceeded, should result in no hearing loss due to noise. A damage risk criterion may include in its statement a specification of such factors as time of exposure, noise level, frequency, amount of hearing loss considered significant, percentage of the population to be protected, and method of measuring the noise.

Damp. A harmful gas or mixture of gases occurring in coal mining.

Dampers. Adjustable sources of airflow resistance used to distribute airflow in a ventilation system.

Dangerous to life or health, immediately (IDLH). Used to describe very hazardous atmospheres where employee exposure can cause serious injury or death within a short time or serious delayed effects.

Daughter. As used in radioactivity, this refers to the product nucleus or atom resulting from decay of the precursor or parent.

dBA. Sound level in decibels read on the A scale of a sound-level meter. The A scale discriminates against very low frequencies (as does the human ear) and is therefore better for measuring general sound levels. See also Decibel.

dBC. Sound level in decibels read on the C scale of a sound-level meter. The C scale discriminates very little against very low frequencies. See also Decibel.

DC. See Direct current.

Decay. When a radioactive atom disintegrates, it is said to decay. What remains is a different element. An atom of polonium decays to form lead, ejecting an alpha particle in the process.

Decibel (dB). A unit used to express sound-power level (L_W) and sound-pressure level (L_P). Sound power is the total acoustic output of a sound source in watts (W). By definition, sound-power level, in decibels, is: $L_W = 10 \log W/W_0$, where W is the sound power of the source and W_0 is the reference sound power of 10^{-12}. Because the decibel is also used to describe other physical quantities, such as electrical current and electrical voltage, the correct reference quantity must be specified.

Decomposition. The breakdown of a chemical or substance into different parts or simpler compounds. Decomposition can occur because of heat, chemical reaction, decay, etc.

Decontaminate. To make safe by eliminating poisonous or otherwise harmful substances, such as noxious chemicals or radioactive material.

Deltoid muscle. The muscle of the shoulder responsible for abducting the arm sideways and for swinging the arm at the shoulder. Overuse of the deltoid muscle may cause fatigue and pain in the shoulder.

Density. The ratio of mass to volume.

Dent-, dento- (prefix)**.** Pertaining to a tooth or teeth, from Latin.

Derma. The dermis. The corium or true skin.

Dermatitis. Inflammation of the skin from any cause.

Dermatology. Branch of medicine concerned with the diagnosis and treatment, including surgery and prevention, of diseases of the skin, hair, and nails.

Dermatophytosis. Athlete's foot.

Dermatosis. A broader term than dermatitis, it includes any cutaneous abnormality. Thus it encompasses folliculitis, acne, pigmentary changes, and nodules and tumors.

Desiccant. Material that absorbs moisture.

Deuterium. Heavy hydrogen. The nucleus of heavy hydrogen is a deuteron. It is called heavy hydrogen because it weighs twice as much as ordinary hydrogen.

Deuteron. The nucleus of an atom of heavy hydrogen containing one proton and one neutron. Deuterons are often used for the bombardment of other nuclei.

Diagnostic x-ray system. An x-ray system designed for irradiation of any part of the human body for the purpose of diagnosis or visualization.

Diaphragm. (1) The musculomembranous partition separating the abdominal and thoracic cavities. (2) Any separating membrane or structure. (3) A disk with one or more openings, or with an adjustable opening, mounted in relation to a lens, by which part of the light may be excluded from the area.

Diatomaceous earth. A soft, gritty amorphous silica composed of minute siliceous skeletons of small aquatic plants. Used in filtration and decolorization of liquids, insulation, filler in dynamite, wax, textiles, plastics, paint, and rubber. Calcined and flux-calcined diatomaceous earth contains appreciable amounts of cristobalite, and dust levels should be controlled the same as for cristobalite.

Die. A hard metal or plastic form used to shape material to a particular contour or section.

Differential pressure. The difference in static pressure between two locations.

Diffuse sound field. One in which the time average of the mean-square sound pressure is everywhere the same and the flow of energy in all directions is equally probable.

Diffusion, molecular. A process of spontaneous intermixing of different substances attributable to molecular motion and tending to produce uniformity of concentration.

Diffusion rate. A measure of the tendency of one gas or vapor to disperse into or mix with another gas or vapor. This rate depends on the density of the vapor or gas as compared with that of air, which is given a value of 1.

Diluent. A liquid blended with a mixture to reduce concentration of the active agents.

Dilution. The process of increasing the proportion of solvent or diluent (liquid) to solute or particulate matter (solid).

Dilution ventilation. See General ventilation.

Diopters. A measure of the power of a lens or prism, equal to the reciprocal of its focal length in meters.

Direct current (DC). Electric current flowing in one direction only.

Direct-reading instrumentation. Instruments that give an immediate indication of the concentration of aerosols, gases, or vapors or magnitude of physical hazard by some means such as a dial or meter.

Disease. A departure from a state of health, usually recognized by a sequence of signs and symptoms.

Disinfectant. An agent that frees from infection by killing the vegetative cells of microorganisms.

Disintegration. A nuclear transformation or decay process that results in the release of energy in the form of radiation.

Dispersion. The general term describing systems consisting of particulate matter suspended in air or other fluid; also, the mixing and dilution of contaminant in the ambient environment.

Distal. Away from the central axis of the body.

Distal phalanx. The last bony segment of a toe or finger.

Distillery. A facility or that portion of a facility where flammable or combustible liquids produced by fermentation are concentrated and where the concentrated products may also be mixed, stored, or packaged.

Diuretic. Anything that promotes excretion of urine.

DNA. Deoxyribonucleic acid. The genetic material within the cell.

DOP. Dioctyl phthalate, a powdered chemical that can be aerosolized to an extremely uniform size, i.e., 0.3 μm for a major portion of any sample.

Dose. (1) Used to express the amount of a chemical or of ionizing radiation energy absorbed in a unit volume or an organ or individual. Dose rate is the dose delivered per unit of time. (See also Roentgen, Rad, Rem.) (2) Used to express amount of exposure to a chemical substance.

Dose, absorbed. The energy imparted to matter in a volume element by ionizing radiation divided by the mass of irradiated material in that volume element.

Dose equivalent. The product of absorbed dose, quality factor, and other modifying factors necessary to express on a common scale, for all ionizing radiations, the irradiation incurred by exposed persons.

Dose equivalent, maximum permissible (MPD). The largest dose equivalent received within a specified period that is permitted by a regulatory agency or other authoritative group on the assumption that receipt of such a dose equivalent creates no appreciable somatic or genetic injury. Different levels of MPD may be set for different groups within a population. (In popular usage, "dose, maximum permissible" is an accepted synonym.)

Dose-response relationship. Correlation between the amount of exposure to an agent or toxic chemical and the resulting effect on the body.

Dosimeter (dose meter). An instrument used to determine the full-shift exposure a person has received to a physical hazard, such as radiation or noise.

DOT. Department of Transportation.

Drier. Any catalytic material that, when added to a drying oil, accelerates drying or hardening of the film.

Drop forge. To forge between dies using a drop hammer or drop press.

Droplet. A liquid particle suspended in a gas. The liquid particle is generally of such size and density that it settles rapidly and remains airborne for an appreciable length of time only in a turbulent atmosphere.

Dross. The scum that forms on the surface of molten metals, consisting largely of oxides and impurities.

Dry-bulb thermometer. An ordinary thermometer, especially one with an unmoistened bulb, not dependent on atmospheric humidity. The reading is the dry-bulb temperature.

Duct. A conduit used for conveying air at low pressures.

Duct velocity. Air velocity through the duct cross section. When solid particulate material is present in the airstream, the duct velocity must exceed the minimum transport velocity.

Ductile. Capable of being molded or worked, as metals.

Dust collector. An air-cleaning device to remove heavy particulate loadings from exhaust systems before discharge to outdoors; usual range is loadings of 0.003 g/ft^3 (0.007 mg/m^3) and higher.

Dusts. Solid particles generated by handling, crushing, grinding, rapid impact, detonation, and decrepitation of organic or inorganic materials, such as rock, ore, metal, coal, wood, and grain. Dusts do not tend to flocculate, except under electrostatic forces; they do not diffuse in air but settle under the influence of gravity.

Dynometer. Apparatus for measuring force or work output external to a subject. Often used to compare external output with associated physiological phenomena to assess physiological work efficiency.

Dys- (prefix)**.** Difficult, bad. This prefix occurs in a large number of medical words because it is attachable to a term for any organ or process that is not functioning as well as it should.

Dysfunction. Disturbance, impairment, or abnormality of the functioning of an organ.

Dyspnea. Shortness of breath, difficult or labored breathing. More strictly, the sensation of shortness of breath.

Dysuria. Difficulty or pain in urination.

E

EAP. Employee Assistance Program.

Ear. The entire hearing apparatus, consisting of three parts: external ear, the middle ear or tympanic cavity, and the inner ear or labyrinth. Sometimes the pinna is called the ear.

Ecology. The science of the relationships between living organisms and their environments.

-ectomy (suffix)**.** A cutting out; surgical removal. Denotes any operation in which all or part of a named organ is cut out of the body.

Eczema. A skin disease or disorder. Dermatitis.

Edema. A swelling of body tissues as a result of being waterlogged with fluid.

Effective temperature (ET). An arbitrary index that combines into a single value the effects of temperature, humidity, and air movement on the sensation of warmth and cold on the human body.

Effective temperature index. An empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement. The determination of effective temperature requires simultaneous determinations of dry-bulb and wet-bulb temperatures.

Efficiency, fractional. The percentage of particles of a specified size that are removed and retained by a particular type of collector or sampler. A plot of fractional efficiency values versus the respective sized particles yields a fractional efficiency curve that may be related to the total collecting efficiency of air-cleaning or air-sampling equipment.

Efflorescence. A phenomenon whereby a whitish crust of fine crystals forms on a surface. These are usually sodium salts that diffuse from the substrate.

Effluent. Generally something that flows out or forth, like a stream flowing out into a lake. In terms of pollution, an outflow of a sewer, storage tank, canal, or other channel.

Ejector. An air mover consisting of a two-flow system wherein a primary source of compressed gas is passed through a Venturi and the vacuum developed at the throat of the Venturi is used to create a secondary flow of fluid. In the case of air movers for sampling applications, the secondary flow is the sample gas.

Elastomer. In a chemical industry sense, a synthetic polymer with rubber-like characteristics; a synthetic or natural rubber or a soft, rubbery plastic with some degree of elasticity at room temperature.

Electrical precipitators. A device that removes particles from an airstream by charging the particles and collecting the charged particles on a suitable surface.

Electrolysis. The process of conduction of an electric current by means of a chemical solution.

Electromagnetic radiation. The propagation of varying electric and magnetic fields through space at the speed of light, exhibiting the characteristics of wave motion.

Electron. A minute atomic particle possessing a negative electric charge. In an atom the electrons rotate around a small nucleus. The weight of an electron is so infinitesimal that it would take 500 octillion (500 followed by 27 zeros) of them to make a pound. It is only about a two-thousandth of the mass of a proton or neutron.

Electron volt (eV). A small unit of energy. An electron gains this much energy when it is acted upon by one volt. Energies of radioactive materials may be millions of electron volts (MeV), whereas particle accelerators generate energies of billions of electron volts (BeV).

Electroplate. To cover with a metal coating (plate) by means of electrolysis.

Element. Solid, liquid, or gaseous matter that cannot be further decomposed into simpler substances by chemical

means. The atoms of an element may differ physically but do not differ chemically. All atoms of an element contain a definite number of protons and thus have the same atomic number.

ELF. Extremely low frequency electromagnetic field.

Elutriator. A device used to separate particles according to mass and aerodynamic size by maintaining a laminar flow system at a rate that permits the particles of greatest mass to settle rapidly while the smaller particles are kept airborne by the resistance force of the flowing air for longer times and distances. The various times and distances of deposit may be used to determine representative fractions of particle mass and size.

Embryo. The name for the early stage of development of an organism. In humans, the period from conception to the end of the second month.

Emergent beam diameter. Diameter of the laser beam at the exit aperture of the system.

Emery. Aluminum oxide, natural and synthetic abrasive.

Emission factor. Statistical average of the amount of a specific pollutant emitted from each type of polluting source in relation to a unit quality of material handled, processed, or burned.

Emission inventory. A list of primary air pollutants emitted into a given community's atmosphere, in amounts per day, by type of source.

Emission standards. The maximum amount of pollutant permitted to be discharged from a single polluting source.

Emmetropia. A state of perfect vision.

Emphysema. A lung disease in which the walls of the air sacs (alveoli) have been stretched too thin and have broken down.

Emulsifier or emulsifying agent. A chemical that holds one insoluble liquid in suspension in another. Casein, for example, is a natural emulsifier in milk, keeping butterfat droplets dispersed.

Emulsion. A suspension, each in the other, of two or more unlike liquids that usually do not dissolve in each other.

Enamel. A paint-like oily substance that produces a glossy finish to a surface to which it is applied, often containing various synthetic resins. It is lead free, in contrast to the ceramic enamel, that is, porcelain enamel, which contains lead.

Endemic. (1) Present in a community or among a group of people; usually refers to a disease prevailing continually in a region. (2) The continuing prevalence of a disease, as distinguished from an epidemic.

Endo- (prefix)**.** Within, inside of, internal. The endometrium is the lining membrane of the uterus.

Endocrine. Secreting without the means of a duct or tube. The term is applied to certain glands that produce secretions that enter the bloodstream or the lymph directly and are then carried to the particular gland or tissue whose function they regulate.

Endothermic. Characterized by or formed with absorption of heat.

Endotoxin. A toxin that is part of the wall of a microorganism and is released when that organism dies.

Energy density. The intensity of electromagnetic radiation per unit area per pulse expressed in joules per square centimeter.

Engineering controls. Methods of controlling employee exposures by modifying the source or reducing the quantity of contaminants released into the work environment.

Enteric. Intestinal.

Entero- (prefix)**.** Pertaining to the intestines.

Enterotoxin. A toxin specific for cells of the intestine; gives rise to symptoms of food poisoning.

Entrainment velocity. The gas flow velocity, which tends to keep particles suspended and cause deposited particles to become airborne.

Entrance loss. The loss in static pressure of a fluid that flows from an area into and through a hood or duct opening. The loss in static pressure is caused by friction and turbulence resulting from the increased gas velocity and configuration of the entrance area.

Entry loss. Loss in pressure caused by air flowing into a duct or hood.

Enzymes. Delicate chemical substances, mostly proteins, that enter into and bring about chemical reactions in living organisms.

EPA. Environmental Protection Agency.

EPA number. The number assigned to chemicals regulated by the Environmental Protection Agency.

Epicondylitis. Inflammation of certain bony prominences in the area of the elbow, for example, tennis elbow.

Epidemiology. The study of disease in human populations.

Epidermis. The superficial scarfskin or upper (outer) layer of skin.

Epilation. Temporary or permanent loss of body hair.

Epithelioma. Carcinoma of the epithelial cells of the skin and other epithelial surfaces.

Epithelium. The purely cellular, avascular layer covering all the free surfaces—cutaneous, mucous, and serous—including the glands and other structures derived therefrom; for example, the epidermis.

Equivalent chill temperature (ECT). Also known as wind chill index. A temperature index used to account for heat loss from skin exposed to the combined effects of cold temperatures and air speed.

Erg. The force of one dyne acting through a distance of one centimeter. It would be equivalent to the work done by a June bug climbing over a stone 0.5 in. (1 cm) high, or the energy required to ionize about 20 billion molecules of air.

Ergonomics. (1) A multidisciplinary activity dealing with interactions between humans and their total working environment plus stresses related to such environmental ele-

ments as atmosphere, heat, light, and sound as well as all tools and equipment of the workplace. (2) The scientific study of or design of equipment and work tasks and their relation to or fit with the operator.

Erysipeloid. A bacterial infection affecting slaughterhouse workers and fish handlers.

Eryth-, erythro- (prefix)**.** Redness. Erythema is indicated by redness of the skin (including a deep blush). An erythrocyte is a red blood cell.

Erythema. Reddening of the skin.

Erythemal region. Ultraviolet light radiation between 2,800 and 3,200 angstroms (280–320 millimicrons); it is absorbed by the cornea of the eye.

Erythrocyte. A type of red blood corpuscle.

Eschar. The crust formed after injury by a caustic chemical or heat.

Essential oil. Any of a class of volatile, odoriferous oils found in plants and imparting to the plants odor and often other characteristic properties. Used in essence, perfumery, etc.

Esters. Organic compounds that may be formed by interaction between an alcohol and an acid, or by other means. Esters are nonionic compounds, including solvents and natural fats.

Etch. To cut or eat away material with acid or another corrosive substance.

Ethylene oxide. A carcinogenic hospital sterilant regulated by OSHA. Ethylene oxide is also a reproductive hazard.

Etiologic agent. Refers to organisms, substances, or objects associated with the cause of disease or injury.

Etiology. The study or knowledge of the causes of disease.

Eu- (prefix)**.** Well and good. A euthyroid person has a thyroid gland that couldn't be working better. A euphoric person has a tremendous sense of well-being.

Eukaryote. An organism whose cells contain mitochondria and a nuclear membrane. Describes organisms from yeasts to humans.

Eustachian tube. A structure about 2.5 in. (6 cm) long leading from the back of the nasal cavity to the middle ear. It equalizes the pressure of air in the middle ear with that outside the eardrum.

Evaporation. The process by which a liquid is changed to the vapor state.

Evaporation rate. The ratio of the time required to evaporate a measured volume of a liquid to the time required to evaporate the same volume of a reference liquid (ethyl ether) under ideal test conditions. The higher the ratio, the slower the evaporation rate.

Exhalation valve. A device that allows exhaled air to leave a respirator and prevents outside air from entering through the valve.

Exhaust ventilation. The removal of air, usually by mechanical means, from any space. The flow of air between two points is because of a pressure difference between the two points. This pressure difference causes air to flow from the high-pressure to the low-pressure zone.

Exothermic, exothermal. Characterized by or formed with evolution of heat.

Exotoxin. A toxin excreted by a microorganism into the surrounding medium.

Explosive limit. See Flammable limit.

Exposure. Contact with a chemical, biological, or physical hazard.

Extension. Movement whereby the angle between the bones connected by a joint is increased. Motions of this type are produced by contraction of extensor muscles.

Extensor muscles A muscle that, when active, increases the angle between limb segments, for example, the muscles that straighten the knee or elbow, open the hand, or straighten the back.

Extensor tendon. Connecting structure between an extensor muscle and the bone into which it inserts. Examples are the hard, longitudinal tendons found on the back of the hand when the fingers are fully extended.

External mechanical environment. The synthetic physical environment, for example, equipment, tools, machine controls, clothing. Antonym: internal (bio)mechanical environment.

Extravasate. To exude a substance from the body's vessels into tissues.

Extrusion. The forcing of raw material through a die or a form in either a hot or cold state, in a solid state, or in partial solution. Long used with metals and clays, it is now extensively used in the plastic industry.

Eyepiece. Gas-tight, transparent window in a full facepiece through which the wearer may see.

F

Face velocity. Average air velocity into the exhaust system measured at the opening into the hood or booth.

Facepiece. That portion of a respirator that covers the wearer's nose and mouth in a half-mask facepiece, or the nose, mouth, and eyes in a full facepiece. It is designed to make a gas-tight or dust-tight fit with the face and includes the headbands, exhalation valves, and connections for air-purifying device, or respirable gas source, or both.

Facing. In foundry work, the final touch-up work of the mold surface to come in contact with metal is called the facing operation, and the fine powdered material used is called the facing.

Fainting. Technically called syncope, a temporary loss of consciousness as a result of a diminished supply of blood to the brain.

Fallout. Dust particles that contain radioactive fission products resulting from a nuclear explosion. The wind can carry fallout particles many miles.

Fan laws. Statements and equations that describe the relationship between fan volume, pressure, brake horsepower, size, and rotating speed.

Fan rating curve or table. Data that describe the volumetric output of a fan at different static pressures.

Fan static pressure. The pressure added to the system by the fan. It equals the sum of pressure losses in the system minus the velocity pressure in the air at the fan inlet.

Far field (free field). In noise measurement, this refers to the distance from the noise source where the sound-pressure level decreases 6 dBA for each doubling of distance (inverse square law).

Farmer's lung. Fungus infection and ensuing hypersensitivity from grain dust.

Federal Register. Publication of U.S. government documents officially promulgated under the law, documents whose validity depends upon such publication. It is published on each day following a government working day. It is, in effect, the daily supplement to the *Code of Federal Regulations* (*CFR*).

Feral animal. A wild animal, or a domestic animal that has reverted to the wild state.

Fertilizer. Plant food usually sold in a mixed formula containing basic plant nutrients: compounds of nitrogen, potassium, phosphorus, sulfur, and sometimes other minerals.

Fetus. The term used to describe the developing organism (human) from the third month after conception to birth.

FEV. Forced expiratory volume.

Fever. A condition in which the body temperature is above its regular or normal level.

Fibrillation. Very rapid irregular contractions of the muscle fibers of the heart resulting in a lack of synchronism of the heartbeat.

Fibrosis. A condition marked by an increase of interstitial fibrous tissue. Exposures to contaminants via inhalation can lead to fibrosis or scarring of the lung, a particular concern in industrial hygiene.

Film badge. A piece of masked photographic film worn by nuclear workers. It is darkened by nuclear radiation, and radiation exposure can be checked by inspecting the film.

Filter. (1) A device for separating components of a signal on the basis of its frequency. It allows components in one or more frequency bands to pass relatively unattenuated, and it greatly attenuates components in other frequency bands. (2) A fibrous medium used in respirators to remove solid or liquid particles from the airstream entering the respirator. (3) A sheet of material that is interposed between patient and the source of x rays to absorb a selective part of the x rays. (4) A fibrous or membrane medium used to collect dust, fume, or mist air samples.

Filter efficiency. The efficiency of various filters can be established on the basis of entrapped particles (that is, collection efficiency), or on the basis of particles passed through the filter (that is, penetration efficiency).

Filter, HEPA. High-efficiency particulate air filter, one that is at least 99.97 percent efficient in removing thermally generated monodisperse dioctyl phthalate smoke particles with a diameter of 0.0003 mm.

Firebrick. A special clay that is capable of resisting high temperatures without melting or crumbling.

Fire damp. In mining, the accumulation of an explosive gas, chiefly methane gas. Miners call all dangerous underground gases "damps."

Fire point. The lowest temperature at which a material can evolve vapors to support continuous combustion.

Fission. The splitting of an atomic nucleus into two parts accompanied by the release of a large amount of radioactivity and heat. Fission reactions occur only with heavy isotopes, such as uranium-233, uranium-235, and plutonium-239.

Fissionable. A nucleus that undergoes fission under the influence of neutrons, even very slow neutrons.

Fission product. The highly radioactive nuclei into which a fissionable nucleus splits (fissions) under the influence of neutron bombardment.

Flagellum. A flexible, whip-like appendage on cells used as an organ of locomotion.

Flame ionization detector (FID). A direct-reading monitoring device that ionizes gases and vapors with an oxyhydrogen flame and measures the differing electrical currents thus generated.

Flameproofing material. Chemicals that catalytically control the decomposition of cellulose material at flaming temperature. Substances used as fire retardants are borax-boric acid, borax-boric acid diammonium phosphate, ammonium bromide, stannic acid, antimony oxide, and combinations containing formaldehyde.

Flame propagation. See Propagation of flame.

Flammable aerosol. An aerosol that is required to be labeled *Flammable* under the Federal Hazardous Substances Labeling Act (15 USC 1261).

Flammable limits. Flammables have a minimum concentration below which propagation of flame does not occur on contact with a source of ignition. This is known as the lower flammable explosive limit (LEL). There is also a maximum concentration of vapor or gas in air above which propagation of flame does not occur. This is known as the upper flammable explosive limit (UEL). These units are expressed in percent of gas or vapor in air by volume.

Flammable liquid. Any liquid having a flash point below 100 F (37.8 C).

Flammable range. The difference between the lower and upper flammable limits, expressed in terms of percentage of vapor or gas in air by volume, also often called the explosive range.

Flange. A rim or edge added to a hood to reduce the quantity of air entering from behind the hood.

Flash blindness. Temporary visual disturbance resulting from viewing an intense light source.

Flash point. The lowest temperature at which a liquid gives off enough vapor to form an ignitable mixture with air and produce a flame when a source of ignition is present. Two tests are used: open cup and closed cup.

Flask. In foundry work, the assembly of the cope and the drag constitutes the flask. It is the wooden or iron frame containing sand into which molten metal is poured. Some flasks may have three or four parts.

Flexion. Movement whereby the angle between two bones connected by a joint is reduced. Motions of this type are produced by contraction of flexor muscles.

Flexor muscles. A muscle that, when contracting, decreases the angle between limb segments. The principal flexor of the elbow is the brachialis muscle. Flexors of the fingers and the wrist are the large muscles of the forearm originating at the elbow. See Extensor muscles.

Flocculation. The process of forming a very fluffy mass of material held together by weak forces of adhesion.

Flocculator. A device for aggregating fine particles.

Flora, microflora. Microorganisms present in a given situation (such as intestinal flora, soil flora).

Flotation. A method of ore concentration in which the mineral is caused to float due to chemical frothing agents while the impurities sink.

Flotation reagent. Chemical used in flotation separation of minerals. Added to a pulverized mixture of solids and water and oil, it causes preferential nonwetting by water of certain solid particles, making possible the flotation and separation of nonwet particles.

Flow coefficient. A correction factor used for figuring the volume flow rate of a fluid through an orifice. This factor includes the effects of contraction and turbulence loss (covered by the coefficient of discharge), plus the compressibility effect and the effect of an upstream velocity other than zero. Because the latter two effects are negligible in many instances, the flow coefficient is often equal to the coefficient of discharge (see Coefficient of discharge).

Flow meter. An instrument for measuring the rate of flow of a fluid or gas.

Flow, turbulent. Fluid flow in which the fluid moves transversely as well as in the direction of the tube or pipe axis, as opposed to streamline or viscous flow.

Fluid. A substance tending to flow or conform to the outline of its container. It may be liquid, vapor, gas, or solid (such as raw rubber).

Fluorescence. Emission of light from a crystal, after the absorption of energy.

Fluorescent screen. A screen coated with a fluorescent substance so that it emits light when irradiated with x rays.

Fluoroscope. A fluorescent screen mounted in front of an x-ray tube so that internal organs may be examined through their shadow cast by x rays. It may also be used for inspection of inanimate objects.

Fluoroscopy. The practice of examining through the use of an x-ray fluoroscope.

Flux. Usually refers to a substance used to clean surfaces and promote fusion in soldering. However, fluxes of varying chemical nature are used in the smelting of ores, in the ceramic industry, in assaying silver and gold ores, and in other endeavors. The most common fluxes are silica, various silicates, lime, sodium and potassium carbonate, and litharge and red lead in the ceramic industry. See also Soldering, Galvanizing, and Luminous flux.

Fly ash. Finely divided particles of ash entrained in flue gases arising from the combustion of fuel.

Focus (pl. foci)**.** A center or site of a disease process.

Follicle. A small anatomical cavity or deep, narrow-mouthed depression; a small lymph node.

Folliculitis. Infection of a hair follicle, often caused by obstruction by natural or industrial oils.

Fomites. Clothing or other substances that can absorb and transmit contaminants, as in the case of poison ivy.

Footcandle. A unit of illumination. The illumination at a point on a surface that is one foot from, and perpendicular to, a uniform point source of one candle.

Foot-pounds of torque. A measurement of the physiological stress exerted upon any joint during the performance of a task. The product of the force exerted and the distance from the point of application to the point of stress. Physiologically, torque that does not produce motion nonetheless causes work stress, the severity of which depends on the duration and magnitude of the torque. In lifting an object or holding it elevated, torque is exerted and applied to the lumbar vertebrae.

Force. That which changes the state of rest or motion in matter. The SI (International System) unit of measurement is the newton (N).

Fovea. A depression or pit in the center of the macula of the eye; it is the area of clearest vision.

Fractionation. Separation of a mixture into different portions or fractions, usually by distillation.

Free sound field (free field). A field in a homogeneous, isotropic medium free from boundaries. In practice, it is a field in which the effects of the boundaries are negligible over the region of interest. See Far field.

Frequency (in Hz). Rate at which pressure oscillations are produced. One hertz is equivalent to one cycle per second. A subjective characteristic of sound related to frequency is pitch.

Friction factor. A factor used in calculating loss of pressure due to friction of a fluid flowing through a pipe or duct.

Friction loss. The pressure loss caused by friction.

Fuller's earth. A hydrated silica-alumina compound associated with ferric oxide. Used as a filter medium and as a catalyst and catalyst carrier and in cosmetics and insecticides.

Fume. Airborne particulate formed by the condensation of solid particles from the gaseous state. Usually, fumes are generated after initial volatilization from a combustion process, or from a melting process (such as metal fume emitted during welding). Usually less than 1 μm in diameter.

Fume fever. Metal fume fever is an acute condition caused by a brief high exposure to the freshly generated fumes of metals, such as zinc or magnesium, or their oxides.

Functional anatomy. Study of the body and its component parts, taking into account structural features directly related to physiological function.

Fundamental frequency. The lowest component frequency of a periodic quantity.

Fundus. The interior surface of a hollow organ, such as the retina of the eye.

Fungus (pl. fungi)**.** Any of a major group of lower plants that lack chlorophyll and live on dead or other living organisms. Fungi include molds, rusts, mildews, smuts, and mushrooms.

Fusion. (1) The joining of atomic nuclei to form a heavier nucleus, accomplished under conditions of extreme heat (millions of degrees). If two nuclei of light atoms fuse, the fusion is accompanied by the release of a great deal of energy. The energy of the sun is believed to be derived from the fusion of hydrogen atoms to form helium. (2) In welding, the melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence.

FVC. Forced vital capacity.

G

Gage pressure. Pressure measured with respect to atmospheric pressure.

Galvanizing. An old but still used method of providing a protective coating for metals by dipping them in a bath of molten zinc.

Gamete. A mature germ cell. An unfertilized ovum or spermatozoon.

Gamma-rays (gamma radiation). The most penetrating of all radiation. Gamma-rays are very high-energy x rays.

Ganglion (pl. ganglia)**.** A knot or knot-like mass; used as a general term to designate a group of nerve cell bodies located outside of the central nervous system. The term is also applied to certain nuclear groups within the brain or spinal cord.

Gangue. In mining or quarrying, useless chipped rock.

Gas. A state of matter in which the material has very low density and viscosity, can expand and contract greatly in response to changes in temperature and pressure, easily diffuses into other gases, and readily and uniformly distributes itself throughout any container. A gas can be changed to the liquid or solid state only by the combined effect of increased pressure and decreased temperature (below the critical temperature).

Gas chromatography. A gaseous detection technique that involves the separation of mixtures by passing them through a column that enables the components to be held up for varying periods of time before they are detected and recorded.

Gas metal arc-welding (GMAW). An arc-welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work; shielding is obtained entirely from an external supplied gas or gas mixture. Some methods of this process are called MIG or CO_2 welding.

Gas tungsten arc-welding (GTAW). An arc-welding process that produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work; shielding is obtained from a gas or gas mixture. Pressure may or may not be used, and filler metal may or may not be used. This process has sometimes been called TIG welding.

Gastr-, gastro- (prefix)**.** Pertaining to the stomach.

Gastritis. Inflammation of the stomach.

Gate. A groove in a mold to act as a passage for molten metal.

Geiger counter. A gas-filled electrical device that counts the presence of an atomic particle or ray by detecting the ions produced. Sometimes called a Geiger-Müller counter.

General ventilation. System of ventilation consisting of either natural or mechanically induced fresh air movements to mix with and dilute contaminants in the workroom air. This is not the recommended type of ventilation to control contaminants that are toxic.

Genes. The ultimate biological units of heredity.

Genetic effects. Mutations or other changes produced by irradiation of the germ plasm.

Genetically significant dose (GSD). The dose that, if received by every member of the population, would be expected to produce the same total genetic injury to the population as the actual doses received by the various individuals.

Germ. A microorganism; a microbe usually thought of as a pathogenic organism.

Germicide. An agent capable of killing germs.

GI. Gastrointestinal.

Gingival. Pertaining to the gingivae (gums), the mucous membrane, with the supporting fibrous tissue, that overlies the crowns of unerupted teeth and encircles the necks of those that have erupted.

Gingivitis. Inflammation of the gums.

Gland. Any body organ that manufactures some liquid product and secretes it from its cells.

Globe thermometer. A thermometer set in the center of a metal sphere that has been painted black in order to measure radiant heat.

Globulin. General name for a group of proteins that are soluble in saline solutions but not in pure water.

Glossa- (prefix)**.** Pertaining to the tongue.

Glove box. A sealed enclosure in which all handling of items inside the box is carried out through long, impervious gloves sealed to ports in the walls of the enclosure.

Gob. Gob pile is waste mineral material, such as from coal mines, that contains sufficient coal that gob fires may arise from spontaneous combustion.

Gonads. The male (testes) and female (ovaries) sex glands.

Grab sample. A sample taken within a very short time period to determine the constituents at a specific time.

Gram (g). A metric unit of weight. One ounce equals 28.4 grams.

Grams per kilogram (g/kg). This indicates the dose of a substance given to test animals in toxicity studies.

Granuloma. A mass or nodule of chronically inflamed tissue with granulations; usually associated with an infective process.

Graticule. See Reticle.

Gravimetric. Pertaining to measurement by weight.

Gravimetric method. A procedure dependent upon the formation or use of a precipitate or residue, which is weighed to determine the concentration of a specific contaminant in a previously collected sample.

Gravitation. The universal attraction existing between all material bodies. The gravitational attraction of the earth's mass for bodies at or near its surface is called gravity.

Gravity, specific. The ratio of the mass of a unit volume of a substance to the mass of the same volume of a standard substance at a standard temperature. Water at 39.2 F (4 C) is the standard substance usually referred to. For gases, dry air, at the same temperature and pressure as the gas, is often taken as the standard substance.

Gravity, standard. A gravitational force that produces an acceleration equal to 32.17 ft (9.8 m) per second. The actual force of gravity varies slightly with altitude and latitude. The standard was arbitrarily established as that at sea level and 45-degree latitude.

Gray (Gy). Unit of absorbed radiation dose equal to one joule of absorbed energy per kilogram of matter; also equal to 100 rad.

Gray iron. The same as cast iron; in general, any iron with high carbon content.

Grooving. Designing a tool with grooves on the handle to accommodate the fingers of the user—a bad practice because of the great variation in the size of workers' hands. Grooving interferes with sensory feedback. Intense pain may be caused by the grooves to the arthritic hand.

Gyn-, gyne- (prefix)**.** Woman, female.

Gynecology. The medical specialty concerned with diseases of women.

Gyratory crusher. A device for crushing rock by means of a heavy steel pestle rotating in a steel cone, with the rock being fed in at the top and passing out of the bottom.

H

Half-life, radioactive. For a single radioactive decay process, the time required for the activity to decrease to half its value by that process.

Half-thickness. The thickness of a specified absorbing material that reduces the dose rate to one half its original value.

Half-value layer (HVL). The thickness of a substance necessary to reduce the intensity of a beam of gamma or x rays to half its original value. Also known as half-thickness.

Halogenated hydrocarbon. A chemical material that has carbon plus one or more of these elements: chlorine, fluorine, bromine, and iodine.

Hammer mill. A machine for reducing the size of stone or other bulk material by means of hammers usually placed on a rotating axle inside a steel cylinder.

Hardness. A relative term to describe the penetrating quality of radiation. The higher the energy of the radiation, the more penetrating (harder) is the radiation.

Hardness of water. A degree of hardness is the equivalent of one grain of calcium carbonate, $CaCO_3$, in one gallon of water.

Hazardous material. Any substance or compound that has the capability of producing adverse effects on the health and safety of humans.

Hazwoper. Hazardous waste operations and emergency response—an OSHA standard intended to protect workers engaged in hazardous waste operations.

Heading. In mining, a horizontal passage or drift of a tunnel, also the end of a drift or gallery. In tanning, a layer of ground bark over the tanning liquor.

Health physicist. A professional person specially trained in radiation physics and concerned with problems of radiation damage and protection.

Hearing conservation. The prevention or minimizing of noise-induced deafness through the use of hearing protection devices, the control of noise through engineering methods, annual audiometric tests, and employee training.

Hearing level. The deviation in decibels of an individual's threshold from the zero reference of the audiometer.

Heat cramps. Painful muscle spasms as a result of exposure to excess heat.

Heat exhaustion. A condition usually caused by loss of body water because of exposure to excess heat. Symptoms include headache, tiredness, nausea, and sometimes fainting.

Heat, latent. The quantity of heat absorbed or given off per unit weight of material during a change of state, such as ice to water or water to steam.

Heat of fusion. The heat given off by a liquid freezing to a solid or gained by a solid melting to a liquid, without a change in temperature.

Heat of vaporization. The heat given off by a vapor condensing to a liquid or gained by a liquid evaporating to a vapor, without a change in temperature.

Heat rash. Itchy rash caused by sweating and inadequate hygiene practices.

Heat, sensible. Heat associated with a change in temperature; specific heat exchange with environment, in contrast to a heat interchange in which only a change of state (phase) occurs.

Heat, specific. The ratio of the quantity of heat required to raise the temperature of a given mass of any substance one degree to the quantity required to raise the temperature of an equal mass of a standard substance (usually water at 59 F [15 C]) one degree.

Heat stress. Relative amount of thermal strain from the environment.

Heat stress index (HSI). Also known as the Belding-Hatch heat stress index, this index combines the environmental heat and metabolic heat into an expression of stress in terms of requirement for evaporation of sweat.

Heatstroke. A serious disorder resulting from exposure to excess heat. It results from sweat suppression and increased storage of body heat. Symptoms include hot dry skin, high temperature, mental confusion, convulsions, and coma. Heatstroke is fatal if not treated promptly.

Heat syncope. A heat-related disorder characterized by symptoms of blurred vision and brief fainting spells, heat syncope is caused by pooling of blood in the legs or skin during prolonged static postures in a hot environment.

Heat treatment. Any of several processes of metal modification, such as annealing.

Heavy hydrogen. Same as deuterium.

Heavy metals. Metallic elements with high molecular weights.

Heavy water. Water containing heavy hydrogen (deuterium) instead of ordinary hydrogen. It is widely used in reactors to slow down neutrons.

Helmet. A device that shields the eyes, face, neck, and other parts of the head.

Hem-, Hemato-, -em- (prefix**).** Pertaining to blood. *Hematuria* means blood in the urine. When the roots occur internally in a word, the *h* is often dropped for the sake of pronunciation, leaving *em* to denote blood, as in anoxemia (deficiency of oxygen in the blood).

Hematology. Study of the blood and the blood-forming organs.

Hematuria. Blood in the urine.

Hemi- (prefix**).** Half. The prefix is straightforward enough in *hemiplegia*, "half paralysis," affecting one side of the body. It is not so plain in *migraine* (one-sided headache), a word that shows how language changes through the centuries. The original word was *hemicrania*, "half-head."

Hemoglobin. The red coloring matter of the blood that carries the oxygen.

Hemolysis. Breakdown of red blood cells with liberation of hemoglobin.

Hemoptysis. Bleeding from the lungs, spitting blood, or blood-stained sputum.

Hemorrhage. Bleeding; especially profuse bleeding, as from a ruptured or cut blood vessel (artery or vein).

Hemorrhagic. Pertaining to or characterized by hemorrhage.

HEPA filter. High efficiency particulate air filter. A disposable, extended-medium, dry-type filter with a particle removal efficiency of no less than 99.97 percent for 0.3 μm particles.

Hepatitis. Inflammation of the liver.

Hepatitis B. A virus causing hepatitis. The virus may also cause liver cancer in some of those infected by it. The virus is bloodborne and as such is one of the agents targeted by OSHA's bloodborne pathogen standard.

Hepatotoxin. Chemicals that produce liver damage.

Herpes. An acute inflammation of the skin or mucous membranes, characterized by the development of groups of vesicles on an inflammatory base.

Hertz. The frequency measured in cycles per second. 1 cps = 1 Hz.

High frequency loss. Refers to a hearing deficit starting with 2000 Hz and beyond.

HIV. Human immunodeficiency virus. Held to be the initiating cause of acquired immunodeficiency syndrome (AIDS).

Homeotherm. Uniform body temperature, or a warm-blooded creature remaining so regardless of environment.

Homogenizer. A machine that forces liquids under high pressure through a perforated shield against a hard surface to blend or emulsify the mixture.

Homoiotherm. See Homeotherm.

Hood. (1) Enclosure, part of a local exhaust system. (2) A device that completely covers the head, neck, and portions of the shoulders.

Hood entry loss. The pressure loss from turbulence and friction as air enters the ventilation system.

Hood, slot. A hood consisting of a narrow slot leading into a plenum chamber under suction to distribute air velocity along the length of the slot.

Hood static pressure. The suction or static pressure in a duct near a hood. It represents the suction that is available to draw air into the hood.

Hormones. Chemical substances secreted by the endocrine glands, exerting influence over practically all body activities.

Horsepower. A unit of power, equivalent to 33,000 foot-pounds per minute (746 W). See Brake horsepower.

Host. A plant or animal harboring another as a parasite or as an infectious agent.

Hot. In addition to meaning having a relatively high temperature, this is a colloquial term meaning highly radioactive.

HSI. See Heat stress index.

Human-equipment interface. Areas of physical or perceptual contact between person and equipment. The design characteristics of the human-equipment interface determine the quality of information. Poorly designed interfaces may lead to excessive fatigue or localized trauma, e.g., calluses.

Humerus. The bone of the upper arm that starts at the shoulder joint and ends at the elbow. Muscles that move the upper arm, forearm, and hand are attached to this bone.

Humidify. To add water vapor to the atmosphere; to add water vapor or moisture to any material.

Humidity. (1) Absolute humidity is the weight of water vapor per unit volume: pounds per cubic foot or grams per cubic centimeter. (2) Relative humidity is the ratio of the actual partial vapor pressure of the water vapor in a

space to the saturation pressure of pure water at the same temperature.

Humidity, specific. The weight of water vapor per unit weight of dry air.

HVAC system. Heating, ventilating, and air conditioning system.

Hyalinization. Conversion into a substance resembling glass.

Hydration. The process of converting raw material into pulp by prolonged beating in water; to combine with water or the elements of water.

Hydrocarbons. Organic compounds composed solely of carbon and hydrogen. Several hundred thousand molecular combinations of C and H are known to exist. Basic building blocks of all organic chemicals. Main chemical industry sources of hydrocarbons are petroleum, natural gas, and coal.

Hydrogenation. A reaction of molecular hydrogen with numerous organic compounds. An example is the hydrogenation of olefins to paraffins or of the aromatics to the naphthenes or the reduction of aldehydes and ketones to alcohols.

Hydrolysis. The interaction of water with a material resulting in decomposition.

Hydrometallurgy. Science of metal recovery by a process involving treatment of ores in an aqueous medium, such as acid or cyanide solution.

Hydrophobic. Repelled by water, or water-hating.

Hygroscopic. Readily absorbing or retaining moisture.

Hyper- (prefix)**.** Over, above, increased. The usual implication is overactivity or excessive production, as in hyperthyroidism.

Hyperkeratosis. Hypertrophy of the horny layer of the skin.

Hypertension. Abnormally high tension; especially high blood pressure.

Hypertrophy. Increase in cell size causing an increase in the size of the organ or tissue.

Hypnotic. Anything that induces sleep or that produces the effects ascribed to hypnotism.

Hypo- (prefix). Under, below; less, decreased. The two different meanings of this common prefix can be tricky. *Hypodermic* might reasonably be interpreted to mean that an unfortunate patient has too little skin. The actual meaning is "under or beneath the skin," a proper site for an injection. The majority of *hypo-* words, however, denote an insufficiency, lessening, or reduction from the norm, as in *hypoglycemia*, meaning too little glucose in the blood.

Hypothermia. A systemic effect of cold stress; condition of reduced body temperature.

Hysteresis. A retardation of the effect when the forces acting upon a body are changed (as if from viscosity or internal friction). Specifically, the magnetization of a sample of iron or steel actually lags behind the magnetic field that induced it, when the field varies.

I

IAQ. Indoor air quality.

IARC. International Agency for Research on Cancer.

Iatro- (prefix)**.** Pertaining to a doctor. A related root, *-atrist*, denotes a specialist, as in *psychiatrist*.

Iatrogenic. Caused by the doctor.

ICC. Interstate Commerce Commission.

ICRP. International Commission on Radiological Protection and Measurements.

Idio- (prefix)**.** Peculiar to, private, or distinctive, as in *idiosyncrasy*.

Idiopathic. Disease that originates in itself.

Idiosyncrasy. A special susceptibility to a particular substance introduced into the body.

IDLH. Immediately dangerous to life or health.

IES. Illumination Engineering Society.

Iliac crest. The upper rounded border of the hip bone. No muscles cross the iliac crest, which lies immediately below the skin. It is an important anatomical reference point because it can be felt through the skin. Seat backrests should clear the iliac crest.

Image. The fluorescent picture produced by x rays hitting a fluoroscopic screen.

Image receptor. Any device, such as a fluorescent screen or radiographic film, that transforms incident x-ray photons either into a visible image or into another form that can be made into a visible image by further transformations.

Immiscible. Not miscible. Any liquid that does not mix with another liquid, in which case the result is two separate layers or cloudiness or turbidity.

Immune. Resistant to disease.

Immunity. The power of the body to successfully resist infection and the effects of toxins. This resistance results from the possession by the body of certain "fighting substances," or antibodies. To immunize is to confer immunity. Immunization is the process of acquiring or conferring immunity.

Impaction. The forcible contact of particles of matter; a term often used synonymously with impingement, but generally reserved for the case where particles are contacting a dry surface.

Impingement. As used in air sampling, impingement refers to a process for the collection of particulate matter in which a particle-containing gas is directed against a wetted glass plate and the particles are retained by the liquid.

Impinger. A device containing an absorbing liquid used in air sampling for the collection of gaseous or particulate constituents of an airstream directed by the device through the liquid. The impinger draws air at high velocity through a glass nozzle or jet. A commonly used type is called the midget impinger.

Inches of mercury column. A unit used in measuring pressures. One inch of mercury column equals a pressure of 0.491 lb/in.^{2} (1.66 kPa).

Inches of water column. A unit used in measuring pressures. One inch of water column equals a pressure of 0.036 lb/in.^{2} (0.25 kPa).

Incompatible. A term applied to liquid and solid systems to indicate that one material cannot be mixed with another specified material without the possibility of a dangerous reaction.

Incubation. Holding cultures of microorganisms under conditions favorable to their growth.

Incubation time. The elapsed time between exposure to infection and the appearance of disease symptoms, or the time period during which microorganisms inoculated into a medium are allowed to grow.

Inductively coupled plasma (ICP). Radiofrequency induced high temperature plasma utilized for analysis of metals either by atomic emission spectrometry or mass spectrophotometry.

Induration. Heat hardening that may involve little more than thermal dehydration.

Inert (chemical)**.** Not having active properties.

Inert gas. A gas that does not normally combine chemically with the base metal or filler metal.

Inert gas welding. An electric welding operation using an inert gas such as helium to flush away the air to prevent oxidation of the metal being welded.

Inertial moment. As related to biomechanics, that moment of force-time caused by sudden accelerations or decelerations. Whiplash of the neck is caused by an inertial moment. In an industrial setting, sidestepping causes application of a lateral inertial moment on the lumbosacral joint, which may cause trauma, pain, and in any case lowers performance efficiency. The inertial moment is one of the seven elements of a lifting task.

Infection. Entrance into the body or its tissues of disease-causing organisms with the effect of damage to the body as a whole or to tissues or organs. It also refers to the entrance into the body of parasites, like certain worms. On the other hand, parasites such as mites and ticks that attack the surface of the body are said to infest, not infect.

Infectious. Capable of invading a susceptible host, replicating and causing an altered host reaction, commonly referred to as a disease.

Infestation. Invasion of the body surface by parasites. See Infection.

Inflammation. The reaction of body tissue to injury, whether by infection or trauma. The inflamed area is red, swollen, hot, and usually painful.

Infrared. Wavelengths of the electromagnetic spectrum longer than those of visible light and shorter than radio waves, 10^{-4}–10^{-1} cm wavelength.

Infrared radiation. Electromagnetic energy with wavelengths from 770 nm to 12,000 nm.

Ingestion. (1) The process of taking substances into the stomach, such as food, drink, or medicine. (2) With regard to certain cells, the act of engulfing or taking up bacteria and other foreign matter.

Ingot. A block of iron or steel cast in a mold for ease in handling before processing.

Inguinal region. The abdominal area on each side of the body occurring as a depression between the abdomen and the thigh; the groin.

Inhalation valve. A device that allows respirable air to enter the facepiece and prevents exhaled air from leaving the facepiece through the intake opening.

Inhibition. Prevention of growth or multiplication of microorganisms.

Inhibitor. An agent that arrests or slows chemical action or a material used to prevent or retard rust or corrosion.

Injury. Damage or harm to the body, as the result of violence, infection, or anything else that produces a lesion.

Innocuous. Harmless.

Inoculation. The artificial introduction of microorganisms into a system.

Inorganic. Used to designate compounds that generally do not contain carbon, whose source is matter other than vegetable or animal. Examples are sulfuric acid and salt. Exceptions are carbon monoxide and carbon dioxide.

Insomnia. Inability to sleep; abnormal wakefulness.

Instantaneous radiation. The radiation emitted during the fission process. These instantaneous radiations are often called prompt gamma-rays or prompt neutrons. Most fission products continue to emit radiation after the fission process.

Inter- (prefix)**.** Between.

Intermediate. A chemical formed as a middle step in a series of chemical reactions, especially in the manufacture of organic dyes and pigments. In many cases, it may be isolated and used to form a variety of desired products. In other cases, the intermediate may be unstable or used up at once.

Internal biomechanical environment. The muscles, bones and tissues of the body, all of which are subject to the same Newtonian force as external objects in their interaction with other bodies and natural forces. When designing for the body, one must consider the forces that the internal biomechanical environment must withstand.

Interphalangeal joints. The finger or toe joints. The thumb has one interphalangeal joint; the fingers have two interphalangeal joints each.

Interstitial. (1) Pertaining to the small spaces between cells or structures. (2) Occupying the interstices of a tissue or organ. (3) Designating connective tissue occupying spaces between the functional units of an organ or a structure.

Intoxication. Either drunkenness or poisoning.

Intra- (prefix)**.** Within.

Intraperitoneal. Inside the space formed by the membrane that lines the interior wall of the abdomen and covers the abdominal organs.

Intravenous. Into or inside the vein.

Intrinsically safe. Said of an instrument that is designed and certified to be operated safely in flammable or explosive atmospheres.

Inverse square law. The propagation of energy through space is inversely proportional to the square of the distance it must travel. An object 3 m away from an energy

source receives one-ninth as much energy as an object 1 m away.

Inversion. Phenomenon of a layer of cool air trapped by a layer of warmer air above it so that the bottom layer cannot rise. This is a special problem in polluted areas because the contaminating substances cannot be dispersed.

Investment casting. There are numerous types of investment casting, and the materials include fire clay, silicon dioxide, silica flour, stillimanite, cristobalite, aluminum oxide, zirconium oxide, and others. The Mercast process uses mercury poured into a steel die. A ceramic shell mold is built around the pattern, and then the pattern is frozen. The mercury is subsequently recovered at room temperature. The potential harm from exposure to mercury often is unrecognized.

Ion. An electrically charged atom. An atom that has lost one or more of its electrons is left with a positive electrical charge. Those that have gained one or more extra electrons are left with a negative charge.

Ion-exchange resin. Synthetic resins containing active groups that give the resin the property of combining with or exchanging ions between the resin and a solution.

Ionization. The process whereby one or more electrons is removed from a neutral atom by the action of radiation. Specific ionization is the number of ion pairs per unit distance in matter, usually air.

Ionization chamber. A device roughly similar to a Geiger counter and used to measure radioactivity.

Ionizing radiation. (1) Electrically charged or neutral particles. (2) Electromagnetic radiation that interacts with gases, liquids, or solids to produce ions. There are five major types: alpha, beta, x- (or x-ray), gamma, and neutrons.

Ion pair. A positively charged atom (ion) and an electron formed by the action of radiation on a neutral atom.

Irradiation. The exposure of something to radiation.

Irritant. A substance that produces an irritating effect when it contacts skin, eyes, nose, or respiratory system.

Ischemia. Loss of blood supply to a particular part of the body.

Ischial tuberosity. A rounded projection on the ischium. It is a point of attachment for several muscles involved in moving the femur and the knee. It can be affected by improper chair design and by situations involving trauma to the pelvic region. When seated, pressure is borne at the site of the ischial tuberosities. Chair design should provide support to the pressure projection of the ischial tuberosity through the skin of the buttocks.

Isometric work. Refers to a state of muscular contraction without movement. Although no work in the "physics" sense is done, physiological work (energy use and heat production) occurs. In isometric exercise, muscles are tightened against immovable objects. In work measurements, isometric muscular contractions must be considered as a major factor of task severity.

Isotope. One of two or more atomic species of an element differing in atomic weight but having the same atomic number. Each contains the same number of protons but a different number of neutrons. Uranium-238 contains 92 protons and 146 neutrons; the isotope U-235 contains 92 protons and 143 neutrons. Thus the atomic weight (atomic mass) of U-238 is 3 higher than that of U-235. See also Radioisotope.

Isotropic. Exhibiting properties with the same values when measured along axes in all directions.

-itis (suffix)**.** Inflammation.

J

Jaundice. Icterus. A serious symptom of disease that causes the skin, the whites of the eyes, and even the mucous membranes to turn yellow.

Jigs and fixtures. Often used interchangeably; precisely, a jig holds work in position and guides the tools acting on the work, whereas a fixture holds but does not guide.

Joint. Articulation between two bones that may permit motion in one or more planes. They may become the sites for work-induced trauma (such as tennis elbow or arthritis) or other disorders.

Joule. Unit of energy used in describing a single pulsed output of a laser. It is equal to one watt-second or 0.239 calories. It equals 1×107 ergs.

Joule/cm^2 (J/cm^2). Unit of energy density used in measuring the amount of energy per area of absorbing surface or per area of a laser beam. It is a unit for predicting the damage potential of a laser beam.

K

Kaolin. A type of clay composed of mixed silicates and used for refractories, ceramics, tile, and stoneware. In some deposits, free silica may be present as an impurity.

Kaolinosis. A condition induced by inhalation of the dust released in the grinding and handling of kaolin (china clay).

Kelvin scale. The fundamental temperature scale, also called the absolute or thermodynamic scale, in which the temperature measure is based on the average kinetic energy per molecule of a perfect gas. The zero of the Kelvin scale is –273.18 degrees Celsius.

Keratin. Sulfur-containing proteins that form the chemical basis for epidermis tissues; found in nails, hair, and feathers.

Keratinocyte. An epidermal cell that produces keratin.

Keratitis. Inflammation of the cornea.

Kev. A unit of energy equal to 1,000 electron volts.

Kilocurie. 1,000 curies. A unit of radioactivity.

Kilogram (kg). A unit of weight in the metric system equal to 2.2 lb.

Kinesiology. The study of human movement in terms of functional anatomy.

Kinetic energy. Energy due to motion. See Work.

Kyphosis. Abnormal curvature of the spine of the upper back in the anteroposterior plane.

L

Laboratory-acquired infection. Any infection resulting from exposure to biohazardous materials in a laboratory environment. Exposure may be the result of a specific accident or inadequate biohazard control procedure or equipment.

Lacquer. A colloidal dispersion or solution of nitrocellulose or similar film-forming compounds, resins, and plasticizers in solvents and diluents used as a protective and decorative coating for various surfaces.

Laminar airflow. Streamlined airflow in which the entire body of air within a designated space moves with uniform velocity in one direction along parallel flow lines.

LAN. Local area network. A network of computers linked electronically and by software. Located geographically locally, usually in one office or office building.

Lapping. The operation of polishing or sanding surfaces such as metal or glass to a precise dimension.

Laryngitis. Inflammation of the larynx.

Larynx. The organ by which the voice is produced. It is situated at the upper part of the trachea.

Laser. Light amplification by stimulated emission of radiation. Lasers may operate in either pulsed or continuous mode.

Laser light region. A portion of the electromagnetic spectrum including ultraviolet, visible, and infrared light.

Laser system. An assembly of electrical, mechanical, and optical components that includes a laser.

Latent period. The time that elapses between exposure and the first manifestation of damage.

Latex. Originally, a milky extract from the rubber tree, containing about 35 percent rubber hydrocarbon, with the remainder being water, proteins, and sugars. Also applied to water emulsions of synthetic rubbers or resins. In emulsion paints, the film-forming resin is in the form of latex.

Lathe. A machine tool used to perform cutting operations on wood or metal by the rotation of the workpiece.

Latissimus dorsi. A large, flat muscle of the back that originates in the lower back and inserts into the humerus near the armpit. It adducts the upper arm, and when the elbow is abducted, it rotates the arm medially. It is actively used in operating equipment such as the drill press, where a downward pull by the arm is required.

LC_{50}. Lethal concentration that kills 50 percent of the test animals within a specified time. See LD_{50}.

LD_{50}. The dose required to produce the death in 50 percent of the exposed population within a specified time.

Leakage radiation. Radiation emanating from the diagnostic source assembly, except for the useful beam and radiation, produced when the exposure switch or timer is not activated.

Lens, crystalline. Lens of the eye—a transparent biconvex body situated between the anterior chamber (aqueous) and the posterior chamber (vitreous) through which the light rays are further focused on the retina. The cornea provides most of the refractive power of the eye.

Lesion. Injury, damage, or abnormal change in a tissue or organ.

Lethal. Capable of causing death.

Leuk-, leuko- (prefix)**.** White.

Leukemia. A group of malignant blood diseases distinguished by overproduction of white blood cells.

Leukemogenic. Having the ability to cause leukemia.

Leukocyte. White blood cell.

Leukocytosis. An abnormal increase in the number of white blood cells.

Leukopenia. A serious reduction in the number of white blood cells.

Lig- (prefix). Binding. A ligament ties two or more bones together.

Linear accelerator. A machine for speeding up charged particles such as protons. It differs from other accelerators in that the particles move in a straight line at all times instead of in circles or spirals.

Line-voltage regulation. The difference between the no-load and the load-line potentials expressed as a percent of the load-line potential.

Lipo- (prefix)**.** Fat, fatty.

Liquefied petroleum gas. A compressed or liquefied gas usually composed of propane, some butane, and lesser quantities of other light hydrocarbons and impurities; obtained as a by-product in petroleum refining. Used chiefly as a fuel and in chemical synthesis.

Liquid. A state of matter in which the substance is a formless fluid that flows in accord with the law of gravity.

Liter (L). A measure of capacity; one quart equals 0.9 L.

Liver. The largest gland or organ in the body, situated on the right side of the upper part of the abdomen. It has many important functions, including regulating the amino acids in the blood; storing iron and copper for the body; forming and secreting bile, which aids in absorption and digestion of fats; transforming glucose into glycogen; and detoxifying exogenous substances.

Live room. A reverberant room that is characterized by an unusually small amount of sound absorption.

Local exhaust ventilation. A ventilation system that captures and removes the contaminants at the point at which they are being produced before they escape into the workroom air.

Localized. Restricted to one spot or area in the body, and not spread all through it; contrasted with systemic.

Lockout/tagout. A basic safety concept and OSHA standard requiring implementation of practices and procedures to prevent the release of potentially hazardous energy from machines or parts of machines and equipment while maintenance, servicing, or alteration activity is performed. The energy in question may be electrical, mechanical, chemical, or any other form. Also called lockout/tagout/blockout.

Lordosis. The curvature of the lower back in the anteroposterior plane.

Loudness. The intensive attribute of an auditory sensation, in terms of which sounds may be ordered on a scale

extending from soft to loud. Loudness depends primarily upon the sound pressure of the stimulus, but it also depends upon the frequency and wave form of the stimulus.

Louver. A slanted panel.

Low-pressure tank. A storage tank designed to operate at pressures between 0.5 and 15 psig (3.5 to 103 kPa).

Lower confidence limit (LCL). In analyzing sampling data, a statistical procedure used to estimate the likelihood that the true value of the sampled quantity is lower than that obtained.

Lower explosive limit (LEL). The lower limit of flammability of a gas or vapor at ordinary ambient temperatures expressed by a percentage of the gas or vapor in air by volume. This limit is assumed constant for temperatures up to 250 F (120 C); above this, it should be decreased by a factor of 0.7, because explosibility increases with higher temperatures.

LP gas. See Liquefied petroleum gas.

Lumbar spine. The section of the lower spinal column or vertebral column immediately above the sacrum. Located in the small of the back and consisting of five large lumbar vertebrae, it is a highly stressed area in work situations and in supporting the body structure.

Lumbosacral joint. The joint between the fifth lumbar vertebrae and the sacrum. Often the site of spinal trauma from lifting tasks.

Lumen. The flux on one square foot of a sphere—one foot in radius—with a light source of one candle at the center that radiates uniformly in all directions.

Luminous flux. The rate of light flow measured in lumens.

Lux. A unit of illumination equal to 10 footcandles.

Lyme disease. A disease transmitted to humans by the deer tick.

Lymph. A pale, coagulable fluid consisting of a liquid portion resembling blood plasma and containing white blood cells (lymphocytes).

Lymph node. Small oval bodies with a gland-like structure scattered throughout the body in the course of the lymph vessels. Also known as lymphatic nodes, lymph glands, and lymphatic glands.

Lymphoid. Resembling lymph.

Lyophilized. Freeze-dried, as in freeze-dried bacterial cultures.

Lysis. The distribution or breaking up of cells by internal or external means.

M

MAC. Maximum allowable concentration.

Maceration. Softening of the skin by action of a liquid.

Macrophage. Immune system cell whose normal function is to engulf and remove foreign matter from the body's tissues.

Macroscopic. Visible without the aid of a microscope.

Macula. An oval area in the center of the retina devoid of blood vessels; the area most responsible for color vision.

Magnification. The number of times the apparent size of an object has been increased by the lens system of a microscope.

Makeup air. Clean, tempered outdoor air supplied to a work space to replace air removed by exhaust ventilation or by some industrial process.

Malaise. A vague feeling of bodily discomfort.

Malignant. As applied to a tumor, cancerous and capable of undergoing metastasis (invasion of surrounding tissue).

Manometer. Instrument for measuring pressure; essentially a U-tube partially filled with a liquid (usually water, mercury, or a light oil) and constructed in such a way that the amount of displacement of the liquid indicates the pressure being exerted on the instrument.

Maser. Microwave amplification by stimulated emission of radiation. When used in the term *optical maser*, it is often interpreted as molecular amplification by stimulated emission of radiation.

Masking. The stimulation of a person's ear with controlled noise to prevent that person from hearing with one ear the tone or signal given to the other ear. This procedure is used when there is at least a 15- to 20-dBA difference in the hearing level between ears.

Mass. Quantity of matter; measured in grams or pounds.

Material safety data sheet (MSDS). As part of hazard communication standards (right-to-know laws), federal and state OSHA programs require manufacturers and importers of chemicals to prepare compendia of information on their products. Categories of information that must be provided on MSDSs include physical properties, recommended exposure limits, personal protective equipment, spill-handling procedures, first aid, health effects, and toxicological data.

Matter. Anything that has mass or occupies space.

Maximum evaporative capacity. The maximum amount of evaporating sweat from a person that an environment can accept.

Maximum line current. The rms current in the supply line of an x-ray machine operating at its maximum rating.

Maximum permissible concentration (MPC). Concentrations set by the National Committee on Radiation Protection (NCRP); recommended maximum average concentrations of radionuclides to which a worker may be exposed assuming that he or she works eight hours a day, five days a week, and 50 weeks a year.

Maximum permissible dose (MPD). A dose of ionizing radiation not expected to cause appreciable bodily injury to a person at any time during his or her life.

Maximum Permissible Exposure (MPE). Analagous to OSHA chemical PELs, MPEs designate maximum exposures for radiofrequency/microwave exposure and laser exposure.

Maximum permissible power or energy density. The intensity of laser radiation not expected to cause detectable bodily injury to a person at any time during his or her life.

Maximum use concentration (MUC). The product of the protection factor of the respiratory protection equipment and the permissible exposure limit (PEL).

Mechanical efficiency curve. A graphical representation of a fan's relative efficiency in moving air at different airflow rates and static pressures.

Mechanotactic stress. Stress caused by contact with a mechanical environment.

Mechanotaxis. Contact with a mechanical environment consisting of forces (pressure, moment), vibration, and so on; one of the ecological stress vectors. Improper design of the mechanotactic interface may lead to instantaneous trauma, cumulative pathogenesis, or death.

Median nerve. A major nerve controlling the flexor muscles of the wrist and hand. Tool handles and other grasped objects should make solid contact with the sensory feedback area of this nerve, located in the palmar surface of the thumb, index finger, middle finger, and part of the ring finger.

Medium. See Culture medium.

Medulla. The part of the brain that controls breathing.

Mega. One million. For example, a megacurie = one million curies.

Mega-, megalo- (prefix)**.** Large, huge. The prefix *macro-* has the same meaning.

Meiosis. The process whereby chromosome pairs undergo nuclear division as the germ cell matures.

Melanoderma. Abnormal darkening of the skin.

Melanocyte. An epidermal cell containing dark pigments.

Melt. In the glass industry, the total batch of ingredients that may be introduced into pots or furnaces.

Melting point. The transition point between the solid and liquid states. Expressed as the temperature at which this change occurs.

Membrane. A thin, pliable layer of animal tissue that covers a surface, lines the interior of a cavity or organ, or divides a space.

Membrane filter. A filter medium made from various polymeric materials such as cellulose, polyethylene, and tetrapolyethylene. These usually exhibit narrow ranges of effective pore diameters and are therefore useful in collecting and sizing microscopic and submicroscopic particles and in sterilizing liquids.

Men-, meno- (prefix) Pertaining to menstruation; from a Greek word for *month.*

Ménière's disease. Of unknown cause, the disease is characterized by episodes of dizziness, nausea, vomiting, tinnitis, and fluctuating hearing loss.

Meson. A particle that weighs more than an electron but generally less than a proton. Mesons can be produced artificially or by cosmic radiation (natural radiation from outer space). Mesons are not stable and disintegrate in a fraction of a second.

Mesothelioma. Cancer of the membranes that line the chest and abdomen.

Metabolism. The flow of energy and the associated physical and chemical changes constantly taking place in the billions of cells that make up the body.

Metal fume fever. A flu-like condition caused by inhaling heated metal fumes.

Metallizing. Melting wire in a special device that sprays the atomized metal onto a surface. The metal can be steel, lead, or another metal or alloy.

Metastasis. Transfer of the causal agent (cell or microorganism) of a disease from a primary focus to a distant one through the blood or lymphatic vessels. Also, spread of malignancy from a site of primary cancer to secondary sites.

Methemoglobinemia. The presence of methemoglobin in the blood. (Methemoglobin is a compound formed when the iron moiety of hemoglobin is oxidized from the ferrous to the ferric state.) This protein inactivates the hemoglobin as an oxygen carrier.

Mev. Million electron volts.

Mica. A large group of silicates of varying composition that are similar in physical properties. All have excellent cleavage and can be split into very thin sheets. Used in electrical insulation.

Microbar. A unit of pressure commonly used in acoustics; equals one dyne/cm^2. A reference point for the decibel, which is accepted as 0.0002 dyne/cm^2.

Microbe. A microscopic organism.

Microcurie (μc). One-millionth of a curie. A still smaller unit is the micromicrocurie (μμc).

Micron (micrometer). A unit of length equal to 10^{-4} cm, approximately 1/25,000 in.

Microorganism. A minute organism—microbes, bacteria, cocci, viruses, and molds, among others.

Microphone. An electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves.

Midsagittal plane. A reference plane formed by bisecting the human anatomy into a right and left aspect. Human motor function can be described in terms of movement relative to the midsagittal plane.

Miliary. Characterized or accompanied by seedlike blisters or inflamed raised portions of tissue.

Milligram (mg). A unit of weight in the metric system. One thousand milligrams equal one gram.

Milligrams per cubic meter (mg/m^3). Unit used to measure air concentrations of dusts, gases, mists, and fumes.

Milliliter (mL). A metric unit used to measure volume. One milliliter equals one cubic centimeter.

Millimeter of mercury (mmHg). The unit of pressure equal to the pressure exerted by liquid mercury one-millimeter-high column at a standard temperature.

Milliroentgen. One one-thousandth of a roentgen.

Millwright. A mechanic engaged in the erection and maintenance of machinery.

Mineral pitch. Tar from petroleum or coal as opposed to wood tar.

Mineral spirits. A petroleum fraction with a boiling range between 300 and 400 F (149 and 240 C).

Miosis. Excessive smallness or contraction of the pupil of the eye.

Mists. Suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, or atomizing. Formed when a finely divided liquid is suspended in air.

Mitosis. Nuclear cell division in which resulting nuclei have the same number and kinds of chromosomes as the original cell.

Mixture. A combination of two or more substances that may be separated by mechanical means. The components may not be uniformly dispersed. See also Solution.

Moderator. A material used to slow neutrons in a reactor. These slow neutrons are particularly effective in causing fission. Neutrons are slowed when they collide with atoms of light elements such as hydrogen, deuterium, and carbon—three common moderators.

Mold. (1) A growth of fungi forming a furry patch, as on stale bread or cheese. See Spore. (2) A hollow form or matrix into which molten material is poured to produce a cast.

Molecule. A chemical unit composed of one or more atoms.

Moment. Magnitude of force times distance of application.

Moment concept. A concept based on theoretical and experimental bases that lifting stress depends on the bending moment exerted at susceptible points of the vertebral column rather than depending on weight alone.

Monaural hearing. Hearing with one ear only.

Monochromatic. Single fixed wavelength.

Monomer. A compound of relatively low molecular weight that, under certain conditions, either alone or with another monomer, forms various types and lengths of molecular chains called polymers or copolymers of high molecular weight. Styrene, for example, is a monomer that polymerizes readily to form polystyrene. See Polymer.

Morphology. The branch of biological science that deals with the study of the structure and form of living organisms.

Motile. Capable of spontaneous movement.

MMVF. Manmade vitreous fibers, such as fiber glass.

MOS. Metal oxide semiconductor. A type of detector used in some direct-reading instruments.

MPE. Maximum Permissible Exposure.

MPL. May be either maximum permissible level, limit, or dose; refers to the tolerable dose rate for humans exposed to nuclear radiation.

Mppcf. Million particles per cubic foot.

mrem. Millirem.

mR. Milliroentgen.

MSHA. The Mine Safety and Health Administration; a federal agency that regulates safety and health in the mining industry.

MSDS. Material safety data sheet.

Mucous membranes. Lining of the hollow organs of the body, notably the nose, mouth, stomach, intestines, bronchial tubes, and urinary tract.

Musculoskeletal system. The combined system of muscles and bones that comprise the internal biomechanical environment.

Mutagen. Anything that can cause a change (mutation) in the genetic material of a living cell.

Mutation. A transformation of the gene that may result in the alteration of characteristics of offspring.

MWD. Megawatt days, usually per ton. The amount of energy obtained from one megawatt power in one day, normally used to measure the extent of nuclear fuel burnup. 10,000 MWD per ton is about 1 percent burnup.

My-, myo- (prefix). Pertaining to muscle. Myocardium is the heart muscle.

Myelo- (prefix). Pertaining to marrow.

N

Nanometer. A unit of length equal to 10^{-7} cm.

Naphthas. Hydrocarbons of the petroleum type that contain substantial portions of paraffins and naphthalenes.

Narcosis. Stupor or unconsciousness produced by chemical substances.

Narcotics. Chemical agents that completely or partially induce sleep.

Narrow band. Applies to a narrow band of transmitted waves, with neither the critical or cutoff frequencies of the filter being zero or infinite.

Nasal septum. Narrow partition that divides the nose into right and left nasal cavities.

Nascent. Just forming, as from a chemical or biological reaction.

Nasopharynx. Upper extension of the throat.

Natural gas. A combustible gas composed largely of methane and other hydrocarbons with variable amounts of nitrogen and noncombustible gases; obtained from natural earth fissures or from driven wells. Used as a fuel in the manufacture of carbon black and in chemical synthesis of many products. Major source of hydrogen for the manufacture of ammonia.

Natural radioactivity. The radioactive background or, more properly, the radioactivity that is associated with the heavy naturally occurring elements.

Natural uranium. Purified from the naturally occurring ore, as opposed to uranium enriched in fissionable content by processing at separation facilities.

Nausea. An unpleasant sensation, vaguely referred to the epigastrium and abdomen. Often precedes vomiting.

NCRP. National Committee on Radiation Protection; an advisory group of scientists and professionals that makes recommendations for radiation protection in the United States.

Near field. In noise measurement, refers to a field in the immediate vicinity of the noise source where the sound-pressure level does not follow the inverse square law.

Necro- (prefix)**.** Dead.

Necrosis. Death of body tissue.

Neoplasm. A cellular outgrowth characterized by rapid cell multiplication; may be benign (semicontrolled and restricted) or malignant.

Nephr-, nephro- (prefix). From the Greek for *kidney*. See also Ren-.

Nephrotoxins. Chemicals that produce kidney damage.

Nephritis. Inflammation of the kidneys.

Neur-, neuro- (prefix). Pertaining to the nerves.

Neural loss. Hearing loss. See also Sensorineural.

Neuritis. Inflammation of a nerve.

Neurological (neurology)**.** The branch of medical science dealing with the nervous system.

Neurotoxin. Chemicals that produce their primary effect on the nervous system.

Neutrino. A particle, resulting from nuclear reactions, that carries energy away from the system but has no mass or charge and is absorbed only with extreme difficulty.

Neutron. A constituent of the atomic nucleus. A neutron weighs about as much as a proton, and has no electric charge. Neutrons make effective atomic projectiles for the bombardment of nuclei.

NFPA. The National Fire Protection Association; a voluntary membership organization whose aim is to promote and improve fire protection and prevention. The NFPA publishes the *National Fire Codes*.

NIOSH. The National Institute for Occupational Safety and Health; a federal agency that conducts research on health and safety concerns, tests and certifies respirators, and trains occupational health and safety professionals.

Nitrogen fixation. Chemical combination or fixation of atmospheric nitrogen with hydrogen, as in the synthesis of ammonia. Bacteria fixates nitrogen in soil. Provides an industrial and agricultural source of nitrogen.

Node. (1) A point, line, or surface in a standing wave where some characteristic of the wave field has essentially zero amplitude. (2) A small, round, or oval mass of tissue; a collection of cells. (3) One of several constrictions occurring at regular intervals in a structure.

Nodule. A small mass of rounded or irregularly shaped cells or tissue; a small node.

Nodulizing. Simultaneous sintering and drum balling, usually in a rotary kiln.

NOEL. See No observable effect level.

Noise. Any unwanted sound.

Noise-induced hearing loss. Slowly progressive inner-ear hearing loss resulting from exposure to continuous noise over a long period of time, as contrasted to acoustic trauma or physical injury to the ear.

Nonauditory effects of noise. Refers to stress, fatigue, health, work efficiency, and performance effects of loud, continuous noise.

Nonferrous metal. Metal such as nickel, brass, or bronze that does not include any appreciable amount of iron.

Nonionizing radiation. Electromagnetic radiation that does not cause ionization. Includes ultraviolet, laser, infrared, microwave, and radiofrequency radiation.

Nonpolar solvents. The aromatic and petroleum hydrocarbon groups characterized by low dielectric constants.

Nonvolatile matter. The portion of a material that does not evaporate at ordinary temperatures.

No Observable Effect Level (NOEL). In toxicology, the concentration of a substance at (and below) which exposure produces no evidence of injury or impairment.

Normal pulse (conventional pulse). Heartbeat; also, a single output event whose pulse duration is between 200 microseconds and one millisecond.

Nosocomial. (1) Pertaining to a hospital. (2) Disease caused or aggravated by hospital life.

NRC. Nuclear Regulatory Commission of the U.S. Department of Energy.

NTP. National Toxicology Program.

Nuclear battery. A device in which the energy emitted by decay of a radioisotope is first converted to heat and then directly to electricity.

Nuclear bombardment. The shooting of atomic projectiles at nuclei, usually in an attempt to split the atom or to form a new element.

Nuclear energy. The energy released in a nuclear reaction such as fission or fusion. Nuclear energy is popularly, though mistakenly, called atomic energy.

Nuclear explosion. The rapid fissioning of a large amount of fissionable material; creates intense heat, a light flash, a heavy blast, and a large amount of radioactive fission products. These may be attached to dust and debris forming fallout. Nuclear explosions also result from nuclear fusion, which does not produce radioactive fission products.

Nuclear reaction. Result of the bombardment of a nucleus with atomic or subatomic particles or very high energy radiation. Possible reactions are emission of other particles, fission, fusion, and the decay of radioactive material.

Nuclear reactor. A machine for producing a controlled chain reaction in fissionable material. It is the heart of nuclear power facilities, where it serves as a heat source. See Reactor.

Nucleonics. The application of nuclear science and techniques in physics, chemistry, astronomy, biology, industry, and other fields.

Nucleus. The inner core of the atom; consists of neutrons and protons tightly locked together.

Nuclide. A type of atom characterized by its mass number, atomic number, and energy state of the nucleus, provided that the mean life in that state is long enough to be observable.

Nuisance dust. Dust with a long history of little adverse effect on the lungs; does not produce significant organic disease or toxic effect when exposures are kept at reasonable levels.

Null point. The distance from a contaminant source at which the initial energy or velocity of the contaminants is dissipated, allowing the material to be captured by a hood.

N-unit (or n-unit). A measure of radiation dose caused by fast neutrons.

Nutrient. A substance that can be used for food.

Nystagmus. Involuntary movement of the eyeballs.

O

Occupational health nursing (OHN). Specialized nursing practice providing health care service to workers and worker populations.

Occupational Safety and Health Review Commission (OSHRC). An independent body established to review actions of federal OSHA that are contested by employers, employees, or their representatives.

Octave. The interval between two sounds having a basic frequency ratio of two.

Octave band. An arbitrary spread of frequencies. The top frequency in an octave band is always twice the bottom one. The octave band may be referred to by a center frequency.

Ocul-, oculo-, ophthalmo- (prefixes)**.** Refer to the eye; *ophth-* words refer more often to eye diseases.

Odor. That property of a substance that affects the sense of smell.

Odor threshold. The minimum concentration of a substance at which a majority of test subjects can detect and identify the characteristic odor of a substance.

Ohm. The unit of electrical resistance.

Ohm's Law. Voltage in a circuit is equal to the current times the resistance.

Oil dermatitis. Blackheads and acne caused by oils and waxes that plug the hair follicles and sweat ducts.

Olecranon fossa. A depression in the back of the lower end of the humerus in which the ulna bone rests when the arm is straight.

Olefins. A class of unsaturated hydrocarbons characterized by relatively great chemical activity. Obtained from petroleum and natural gas. Examples are butene, ethylene, and propylene. Generalized formula: C_nH_{2n}.

Olfactory. Pertaining to the sense of smell.

Olig-, oligo- (prefix)**.** Scanty, few, little. *Oliguria* means scanty urination.

Oncogenic. Tumor-generating.

Oncology. Study of causes, development, characteristics, and treatment of tumors.

Opacity. The condition of being nontransparent; a cataract.

Ophthalmologist. A physician who specializes in the structure, function, and diseases of the eye.

Optical density (OD). A logarithmic expression of the attenuation afforded by a filter.

Optically pumped laser. A type of laser that derives its energy from a noncoherent light source, such as a xenon flash lamp; usually pulsed and commonly called a solid-state laser.

Organ. An organized collection of tissues that have a special and recognized function.

Organ of Corti. The heart of the hearing mechanism; an aggregation of nerve cells in the ear lying on the basilar membrane that picks up vibrations and converts them to electrical energy, which is sent to the brain and interpreted as sound.

Organic. Chemicals that contain carbon. To date, nearly one million organic compounds have been synthesized or isolated. See also Inorganic.

Organic disease. Disease in which some change in the structure of body tissue could either be visualized or positively inferred from indirect evidence.

Organic matter. Compounds containing carbon.

Organism. A living thing, such as a human being, animal, germ, plant, and so on, especially one consisting of several parts, each specializing in a particular function.

Orifice. (1) The opening that serves as an entrance and/or outlet of a body cavity or organ, especially the opening of a canal or a passage. (2) A small hole in a tube or duct. A critical, or limiting, orifice is used to control rate of flow of a gas in rotometers and other air-sampling equipment.

Orifice meter. A flow meter, employing as the measure of flow rate the difference between pressures measured on the upstream and downstream sides of a restriction within a pipe or duct.

Ortho- (prefix)**.** Straight, correct, normal. Orthopsychiatry is the specialty concerned with "straightening out" behavioral disorders.

Orthoaxis. The true anatomical axis about which a limb rotates, as opposed to the assumed axis. The assumed axis is usually the most obvious or geometric one; the orthoaxis is less evident and can only be found by the use of anatomical landmarks.

Os-, oste-, osteo- (prefix)**.** Pertaining to bone. The Latin *os-* is most often associated with anatomical structures, whereas the Greek *osteo-* usually refers to conditions involving bone. *Osteogenesis* means formation of bone.

Oscillation. The variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference.

OSHA. U.S. Occupational Safety and Health Administration.

OSHA 200 Log. Record keeping of employee injuries and illnesses is required by OSHA standard; OSHA 200 Log is a format that contains the necessary required details. It may be used by employers and is available from OSHA.

Osmosis. The passage of fluid through a semipermeable membrane as a result of osmotic pressure.

Osseous. Pertaining to bone.

Ossicle. Any member of a chain of three small bones from the outer membrane of the tympanum (eardrum) to the membrane covering the oval window of the inner ear.

ot-, oto- (prefix)**.** Pertaining to the ear. *Otorrhea* means ear discharge.

Otitis media. An inflammation and infection of the middle ear.

Otologist. A physician specializing in surgery and diseases of the ear.

Otosclerosis. A condition of the ear caused by a growth of body tissue about the foot plate of the stapes and oval window of the inner ear; results in a gradual loss of hearing.

Output power and output energy. Power is used primarily to rate CW lasers, because the energy delivered per unit time remains relatively constant (output measured in watts). In contrast, pulsed lasers deliver their energy output in pulses and their effects may be best categorized by energy output per pulse. The output power of CW lasers is usually expressed in milliwatts or watts, pulsed lasers in kilowatts, and q-switch pulsed lasers in megawatts or gigawatts. Pulsed energy output is usually expressed as joules per pulse.

Overexposure. Exposure beyond the specified limits.

Oxidation. Process of combining oxygen with some other substance; technically, a chemical change in which an atom loses one or more electrons. Opposite of reduction.

P

PAH. Polynuclear aromatic hydrocarbons are a subset of the particles created during combustion of diesel fuel and are thought to be associated with possible health effects. PAHs are also found in materials other than diesel fuel.

Pair production. The conversion of a gamma ray into a pair of particles: an electron and a positron. This is an example of direct conversion of energy into matter according to Einstein's famous formula, $E = mc^2$: energy = mass × velocity of light squared.

Palmar arch. Blood vessels in the palm of the hand from which the arteries supplying blood to the fingers are branched. Pressure against the palmar arch by poorly designed tool handles may cause ischemia of the fingers and loss of tactile sensation and precision of movement.

Palpitation. Rapid heartbeat of which a person is acutely aware.

Papilloma. A small growth or tumor of the skin or mucous membrane; warts and polyps, for example.

Papule. A small, solid, usually conical elevation of the skin.

Papulovesicular. Characterized by the presence of papules and vesicles.

Para- (prefix). Alongside, near, abnormal; as in *paraproctitis*, inflammation of tissues near the rectum. A Latin suffix with the same spelling, *-para*, denotes bearing or giving birth, as in *multipara*, a woman who has given birth to two or more children.

Paraffins, paraffin series. (From *parum affinis*—small affinity.) Straight- or branched-chain hydrocarbon components of crude oil and natural gas whose molecules are saturated (that is, carbon atoms attached to each other by single bonds) and therefore very stable. Examples are methane and ethane. Generalized formula: C_nH_{2n+2}.

Parasite. An organism that derives its nourishment from a living plant or animal host. Does not necessarily cause disease.

Parenchyma. The distinguishing or specific (working) tissue of a bodily gland or organ, contained in and supported by the connective tissue framework, or stroma.

Parent. Precursor; the name given to a radioactive nucleus that disintegrates to form a radioactive product or daughter.

Partial barrier. An enclosure constructed so that sound transmission between its interior and its surroundings is minimized.

Particle. A small discrete mass of solid or liquid matter.

Particle concentration. Concentration expressed in terms of number of particles per unit volume of air or other gas. When expressing particle concentrations, the method of determining the concentration should be stated.

Particle size. The measured dimension of liquid or solid particles, usually in microns.

Particle size distribution. The statistical distribution of the sizes or ranges of size of a population of particles.

Particulate. A particle of solid or liquid matter.

Particulate matter. A suspension of fine solid or liquid particles in air, such as dust, fog, fume, mist, smoke, or sprays. Particulate matter suspended in air is commonly known as an aerosol.

Particulates Not Otherwise Classified (PNOC). A recent designation replacing the older term "nuisance dusts" for various particulates for which no specific toxicity-related Permissible Exposure Limit exists. The OSHA PEL for all PNOC's is 10 mg/m^3. Also may be represented as Particulates Not Otherwise Regulated (PNOR).

Pascal. A unit used in measuring sound pressure. See also *microbar* and *decibel*.

Path-, patho- (prefix)**, -pathy** (suffix)**.** Feeling, suffering, disease. *Pathogenic* means producing disease; *enteropathy* means disease of the intestines; pathology is the medical specialty concerned with all aspects of disease. The root appears in the everyday word *sympathy* (feeling with).

Pathogen. Any microorganism capable of causing disease.

Pathogenesis. Describes how a disease takes hold on the body and spreads.

Pathogenic. Producing or capable of producing disease.

Pathognomonic. Distinctive or characteristic of a specific disease or pathological condition; a sign or symptom from which a diagnosis can be made.

Pathological. Abnormal or diseased.

Pathology. The study of disease processes.

PCM. See Phase Contrast Microscopy.

PEL. See Permissible Exposure Limit.

Pelleting. In various industries, powdered material may be made into pellets or briquettes for convenience. The pellet is a distinctly small briquette. See Pelletizing.

Pelletizing. Refers primarily to extrusion by pellet mills; also refers to other small extrusions and to some balled products. Generally regarded as being larger than grains and smaller than briquettes.

Percent impairment of hearing (percent hearing loss). An estimate of a person's ability to hear correctly; usually determined by the pure tone audiogram. The specific rule for calculating this quantity varies from state to state according to law.

Percutaneous. Performed through the unbroken skin, as by absorption of an ointment through the skin.

Peri- (prefix)**.** Around, about, surrounding. Periodontium is tissue that surrounds and supports the teeth.

Periodic table. Systematic classification of the elements according to atomic numbers (nearly the same order as by atomic weights) and by physical and chemical properties.

Peripheral neuropathy. Deterioration of peripheral nerve function; affects the hands, arms, feet, and legs. Certain hydrocarbon solvents are known to cause peripheral neuropathies in overexposed individuals.

Permeation. Process by which a chemical moves through a protective clothing material on a molecular level.

Permissible dose. See MPC, MPL.

Permissible Exposure Limit (PEL). An exposure limit published and enforced by OSHA as a legal standard. Most PELs are expressed as eight hour average airborne concentrations of substances to which it is believed most workers may be exposed for a working lifetime without developing serious illness.

Personal monitoring. Measurement of an employee's exposure to airborne contaminants through collection of air samples near the employee's breathing zone and subsequent analysis of the collected sample.

Personal protective equipment. Devices worn by the worker to protect against hazards in the environment. Respirators, gloves, and hearing protectors are examples.

Pesticides. General term for chemicals used to kill such pests as rats, insects, fungi, bacteria, weeds, and so on, that prey on humans or agricultural products. Among these are insecticides, herbicides, fungicides, rodenticides, miticides, fumigants, and repellents.

Petrochemical. A term applied to chemical substances produced from petroleum products and natural gas.

Phase-Contrast Microscopy (PCM). Light microscopy method used to analyze air samples for concentrations of asbestos in fibers per cubic centimeter. Required method in the OSHA asbestos standard.

Pink noise. Noise that has been weighted, especially at the low end of the spectrum, so that the energy per band (usually octave band) is approximately constant over the spectrum.

PH. The degree of acidity or alkalinity of a solution, with neutrality indicated as 7.

Phagocyte. A cell in the body that engulfs foreign material and consumes debris and foreign bodies.

Phalanx (pl. phalanges)**.** Any of the bones of the fingers or toes. Often used as anatomical reference points in ergonomic work analysis.

Pharmaceuticals. Drugs and related chemicals reaching the public primarily through drug suppliers. In government reports, this category includes not only such medicinals as aspirin and antibiotics but also such nutriments as vitamins and amino acids for both human and animal use.

Pharyngeal. Pertaining to the pharynx (the musculomembranous sac between the mouth, nares, and esophagus).

Phenol. C_6H_5OH. Popularly known as carbolic acid. Important chemical intermediate and base for plastics, pharmaceuticals, explosives, antiseptics, and many other end products.

Phenolic resins. A class of resins produced as the condensation product of phenol or substituted phenol and formaldehyde or other aldehydes.

Phosphors. Fluorescent or luminescent materials.

Photochemical process. Chemical changes brought about by radiant energy acting upon various chemical substances. See Photosynthesis.

Photoelectric effect. Occurs when an electron is thrown out of an atom by a light ray or gamma-ray. This effect is used in an "electric eye;" light falls on a sensitive surface throwing out electrons that can then be detected.

Photoionization detector (PID). A direct-reading monitoring instrument that operates by detecting and distinguishing between ions of vapors and gases following ionization by the instrument's ultraviolet light source.

Photomultiplier tube. A vacuum tube that multiplies electron input.

Photon. A bundle (quantum) of radiation. Constitutes, for example, x rays, gamma-rays, and light.

Photophobia. Abnormal sensitivity to light.

Photosynthesis. The process by which plants produce carbohydrates and oxygen from carbon dioxide and water.

Physiology. The study of the functions or actions of living organisms.

Physiopathology. The science of functions in disease or modified by a disease.

Pig. (1) A container (usually lead) used to ship or store radioactive materials. The thick walls protect workers from radiation. (2) In metal refining, a small ingot from the casting of blast furnace metal.

Pigment. A finely divided, insoluble substance that imparts color to a material.

Pilot facility. Small scale operation preliminary to major enterprises. Common in the chemical industry.

Pinna. Ear flap; the part of the ear that projects from the head. Also known as the auricle.

Pitch. The attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high. Pitch depends primarily on the frequency of the

sound stimulus, but also on the sound pressure and wave form of the stimulus.

Pitot tube. A device consisting of two concentric tubes, one serving to measure the total or impact pressure existing in the airstream, the other to measure the static pressure only. When the annular space between the tubes and the interior of the center tube are connected across a pressure-measuring device, the pressure difference automatically nullifies the static pressure, and the velocity pressure alone is registered.

Plasma. (1) The fluid part of the blood in which the blood cells are suspended. Also called protoplasm. (2) A gas that has been heated to a partially or completely ionized condition, enabling it to conduct an electric current.

Plasma arc welding (PAW). A process that produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or between the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained by the hot, ionized gas issuing from the orifice, which may be supplemented by an auxiliary source of shielding gas. Shielding gas can be an inert gas or a mixture of gases. Pressure may or may not be used, and filler metal may or may not be supplied.

Plastics. Any one of a large group of materials that contains as an essential ingredient an organic substance of large molecular weight. Two basic types are thermosetting (irreversibly rigid) and thermoplastic (reversibly rigid). Before compounding and processing, plastics often are referred to as (synthetic) resins. Final form may be a film, sheet, solid, or foam-flexible or rigid.

Plasticizers. Organic chemicals used in modifying plastics, synthetic rubber, and similar materials to facilitate compounding and processing, and to impart flexibility to the end product.

Plenum. Pressure-equalizing chamber.

Plenum chamber. An air compartment connected to one or more ducts or connected to a slot in a hood; used for air distribution.

Pleura. The thin membrane investing the lungs and lining the thoracic cavity, completely enclosing a potential space known as the pleural cavity. There are two pleurae, right and left, entirely distinct from each other. The pleura is moistened with a secretion that facilitates the movements of the lungs in the chest.

Pleurisy. Caused when the outer lung lining (visceral pleura) and the chest cavity's inner lining (parietal pleura) lose their lubricating properties; the resultant friction causes irritation and pain.

PLM. See Polarized Light Microscopy.

Plumbism. One name for lead intoxication.

Plume trap. An exhaust ventilation hood designed to capture and remove the plume given off the target on impact of a laser beam.

Plutonium. A heavy element that undergoes fission under the impact of neutrons. It is a useful fuel in nuclear reactors. Plutonium cannot be found in nature, but can be produced and "burned" in reactors.

PNA. See PAH.

Pneumo- (Greek), pulmo- (Latin) (prefix**).** Pertaining to the lungs.

Pneumoconiosis. Literally "Dusty lungs;" a result of the continued inhalation of various kinds of dust or other particulates; the tissue reaction resulting from the accumulation of such dusts in the lungs.

Pneumoconiosis-producing dust. Dust, which when inhaled, deposited, and retained in the lungs, may produce signs, symptoms, and findings of pulmonary disease.

Pneumonitis. Inflammation of the lungs.

PNOC. See Particulates Not Otherwise Classified.

Poison. (1) A material introduced into the reactor core to absorb neutrons. (2) Any substance that, when taken into the body, is injurious to health.

Polarized Light Microscopy (PLM). Method used to analyze for the presence of asbestos in bulk samples of material. Required method in the OSHA asbestos standard

Polarography. A physical analysis method for determining certain atmospheric pollutants that are electroreducible or electro-oxidizable and are in true solution and stable for the duration of the measurement.

Polar solvents. Solvents (such as alcohols and ketones) that contain oxygen and that have high dielectric constants.

Pollution. Synthetic contamination of soil, water, or atmosphere beyond that which is natural.

Poly- (prefix**).** Many.

Polycythemia. A condition marked by an excess in the number of red corpuscles in the blood.

Polymer. A high molecular-weight material formed by the joining together of many simple molecules (monomers). There may be hundreds or even thousands of the original molecules linked end to end and often cross-linked. Rubber and cellulose are naturally occurring polymers. Most resins are chemically produced polymers.

Polymerization. A chemical reaction in which two or more small molecules combine to form larger molecules (polymers) that contain repeating structural units of the original molecules. A hazardous polymerization is one with an uncontrolled release of energy.

Polystyrene resins. Synthetic resins formed by polymerization of styrene.

Popliteal clearance. Distance between the front of the seating surface and the popliteal crease. This should be about 5 in. in good seat design to prevent pressure on the popliteal artery.

Popliteal crease (or line). The crease in the hollow of the knee when the lower leg is flexed. Important anatomical reference point for ergonomic considerations.

Popliteal height of chair. The height of the highest part of the seating surface above the floor.

Popliteal height of individual. The distance between the crease in the hollow of the knee and the floor.

Porphyrin. One of a group of complex chemical substances that forms the basis of the respiratory pigments of animals and plants; hemoglobin and chlorophyll are other examples.

Portal. Place of entrance.

Portland cement. See Cement, portland.

Positive displacement pump. Any type of air mover pump in which leakage is negligible, so that the pump delivers a constant volume of fluid, building up to any pressure necessary to deliver that volume.

Positron. A particle that has the same weight and charge as an electron but is electrically positive rather than negative. The positron's existence was predicted in theory years before it was actually detected. It is not stable in matter because it reacts readily with an electron to give two gamma-rays.

Potential energy. Energy due to position of one body with respect to another or to the relative parts of the same body.

Power. Rate at which work is done; measured in watts (one joule per second) and horsepower (33,000 foot-pounds per minute). One horsepower equals 746 watts.

Power density. The intensity of electromagnetic radiation per unit area, expressed as watts/cm.

Power level. 10 times the logarithm to the base 10 of the ratio of a given power to a reference power; measured in decibels.

ppb. Parts per billion.

ppm. Parts per million parts of air by volume of vapor or gas or other contaminant.

PPE. See Personal protective equipment.

Precision. The degree of agreement (expressed in terms of distribution of test results about the mean result) of repeated measurements of the same property, obtained by repetitive testing of a homogeneous sample under specified conditions. The precision of a method is expressed quantitatively as the standard deviation, computed from the results of a series of controlled determinations.

Presby- (prefix)**.** Old. As in *presbyopia*—eye changes associated with aging.

Presbycusis. Hearing loss caused by age.

Pressure. Force applied to or distributed over a surface; measured as force per unit area. See Absolute pressure, Atmospheric pressure, Gage pressure, Standard temperature and pressure, Static pressure, Total pressure, Vapor pressure, and Velocity pressure.

Pressure drop. The difference in static pressure measured at two locations in a ventilation system; caused by friction or turbulence.

Pressure loss. Energy lost from a pipe or duct system through friction or turbulence.

Pressure, static. The normal force per unit area that would be exerted by a moving fluid on a small body immersed in it if the body were carried along with the fluid. Practically, it is the normal force per unit area at a small hole in a wall of the duct through which the fluid flows or on the surface of a stationary tube at a point where the disturbances, created by inserting the tube, cancel. The potential pressure exerted in all directions by a fluid at rest. It is the tendency to either burst or collapse the pipe, usually expressed in inches of water gauge (in. wg) when dealing with air.

Pressure, total. In the theory of the flow of fluids, the sum of the static pressure and the velocity pressure at the point of measurement. Also called dynamic pressure.

Pressure, vapor. The pressure exerted by a vapor. If a vapor is kept in confinement at a constant temperature over its liquid so that it can accumulate above the liquid, the vapor pressure approaches a fixed limit called the maximum, or saturated, vapor pressure, dependent only on the temperature and the liquid.

Pressure vessel. A storage tank or vessel designed to operate at pressures greater than 15 psig (103 kPa).

PRF laser. A pulsed recurrence frequency laser, which is a pulsed-typed laser with properties similar to a CW laser when the frequency is very high.

Probe. A tube used for sampling or for measuring pressures at a distance from the actual collection or measuring apparatus; commonly used for reaching inside stacks or ducts.

Process Safety Management (PSM). Systematic evaluation of an entire process for the purpose of preventing unwanted release of chemicals into the work environment. Required by OSHA for certain chemicals when trigger quantities have been reached. In PSM, each step of a chemical process is analyzed for potential hazards.

Prokaryote. Single-celled organism lacking mitochondria and a defined nucleus. Usually has a cell wall. Describes primarily bacterial organisms.

Proliferation. The reproduction or multiplication of similar forms, especially of cells and morbid cysts.

Pronation. Rotation of the forearm in a direction to face the palm downward when the forearm is horizontal, and backward when the forearm is in a vertical position.

Propagation of flame. The spread of flame through the entire volume of a flammable vapor-air mixture from a single source of ignition. A vapor-air mixture below the lower flammable limit may burn at the point of ignition without propagating from the ignition source.

Prophylactic. Preventive treatment for protection against disease.

Protection factor (PF). In respiratory protective equipment, the ratio of the ambient airborne concentration of the contaminant to the concentration inside the facepiece.

Protective atmosphere. A gas envelope surrounding an element to be brazed, welded, or thermal-sprayed, with the gas composition controlled with respect to chemical composition, dew point, pressure, flow rate, and so on.

Protective coating. A thin layer of metal or organic material, applied as paint to a surface to protect it from oxidation, weathering, and corrosion.

Proteins. Large molecules found in the cells of all animal and vegetable matter containing carbon, hydrogen, nitrogen,

and oxygen, and sometimes sulfur and phosphorus. The fundamental structural units of proteins are amino acids.

Proteolytic. Capable of splitting or digesting proteins into simpler compounds.

Proton. A fundamental unit of matter having a positive charge and a mass number of one.

Protoplasm. The basic material from which all living tissue is made. Physically it is a viscous, translucent, semifluid colloid, composed mainly of proteins, carbohydrates, fats, salts, and water.

Protozoa. Single-celled microorganisms belonging to the animal kingdom.

Proximal. The part of a limb that is closest to the point of attachment. The elbow is proximal to the wrist, which is proximal to the fingers.

Psittacosis. Parrot fever. An infectious disease of birds to which poultry handlers and other workers exposed to dried bird feces are at risk. Caused by *Chlamydia psittaci*. The most noted symptom of the disease among humans is fever.

Psych-, psycho- (prefix)**.** Pertaining to the mind, from the Greek word for *soul*.

Psychogenic deafness. Loss originating in or produced by the mental reaction of an individual to their physical or social environment. It is sometimes called functional deafness or feigned deafness.

Psychrometer. An instrument consisting of wet- and dry-bulb thermometers for measuring relative humidity.

Psychrometric chart. A graphical representation of the thermodynamic properties of moist air.

Pterygium. A growth of the conjunctiva caused by a degenerative process brought on by long, continued irritation (as from exposure to wind, dust, and possibly to ultraviolet radiation).

Pulmonary. Pertaining to the lungs.

Pulse length. Duration of a pulsed laser flash; may be measured in milliseconds, microseconds, or nanoseconds.

Pulsed laser. A class of laser characterized by operation in a pulsed mode; that is, emission occurs in one or more flashes of short duration (pulse length).

Pumice. A natural silicate from volcanic ash or lava. Used as an abrasive.

Pupil. The variable aperture in the iris through which light travels toward the interior regions of the eye. The pupil size varies from 2 mm to 8 mm.

Pur-, pus- (Latin), pyo- (Greek) (prefixes)**.** Indicates pus, as in *purulent, suppurative, pustulant*, and *pyoderma*.

Pure tone. A sound wave characterized by its singleness of frequency.

Purpura. Extensive hemorrhage into the skin or mucous membrane.

Push-pull hood. A hood consisting of an air supply system on one side of the contaminant source blowing across the source and into an exhaust hood on the other side.

Putrefaction. Decomposition of proteins by microorganisms, producing disagreeable odors.

Pyloric stenosis. Obstruction of the pyloric opening of the stomach caused by hypertrophy of the pyloric sphincter.

Pylorus. The orifice of the stomach leading to the small intestine.

Pyel-, pyelo- (prefix)**.** Pertaining to the urine-collecting chamber of the kidney.

Pyr-, pyret- (prefix)**.** Fever.

Pyrethrum. A pesticide obtained from the dried, powdered flowers of the plant of the same name; mixed with petroleum distillates, it is used as an insecticide.

Pyrolysis. The breaking apart of complex molecules into simpler units by the use of heat, as in the pyrolysis of heavy oil into gasoline.

Q

QF. See Quality factor.

Q fever. Disease caused by a rickettsial organism that infects meat and livestock handlers; similar but not identical to tick fever.

Q-switched laser. (Also known as Q-spoiled). A pulsed laser capable of extremely high peak powers for very short durations (pulse length of several nanoseconds).

Qualitative fit testing. A method of assessing the effectiveness of a particular size and brand of respirator based on an individual's subjective response to a test atmosphere. The most common test agents are isoamyl acetate (banana oil), irritant smoke, and sodium saccharin. Proper respirator fit is indicated by the individual reporting no indication of the test agent inside the facepiece during the performance of a full range of facial movements.

Quality. A term used to describe the penetrating power of x rays or gamma-rays.

Quality factor. A linear energy transfer-dependent factor by which absorbed radiation doses are to be multiplied to obtain the dose equivalent.

Quantitative fit testing. A method of assessing the effectiveness of a particular size and brand of respirator on an individual. Instrumentation is used to measure both the test atmosphere (a gas, vapor or aerosol, such as DOP) and the concentration of the test contaminant inside the facepiece of the respirator. The quantitative fit factor thus obtained is used to determine if a suitable fit has been obtained by referring to a table or to the software of the instrumentation. Quantitative fit factors obtained in this way do not correlate well with Assigned Protection Factors, which are based on actual measurements of levels of contaminant inside the facepiece during actual work.

Quantum. "Bundle of energy"; discrete particle of radiation. Pl. quanta.

Quartz. Vitreous, hard, chemically resistant, free silica, the most common form in nature. The main constituent in sandstone, igneous rocks, and common sands.

Quenching. A heat-treating operation in which metal raised to the desired temperature is quickly cooled by immersion in an oil bath.

R

Rabbit. A capsule that carries samples in and out of an atomic reactor through a pneumatic tube in order to permit study of the effect of intense radiation on various materials.

Rad. Roentgen absorbed dose or radiation absorbed dose; a standard unit of absorbed ionizing radiation dose equal to 100 ergs absorbed per gram.

Radial deviation. Flexion of the hand that decreases the angle between its longitudinal axis and radius. Tool design should minimize radial deviation. Strength of grasp is diminished in radial deviation.

Radian. An arc of a circle equal in length to the radius.

Radiant temperature. The temperature resulting from a body absorbing radiant energy.

Radiation (nuclear**).** The emission of atomic particles or electromagnetic radiation from the nucleus of an atom.

Radiation protection guide (RPG). The radiation dose that should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

Radiation (radioactivity**).** See Ionizing radiation.

Radiation source. An apparatus or material emitting or capable of emitting ionizing radiation.

Radiation (thermal**).** The transmission of energy by means of electromagnetic waves longer than visible light. Radiant energy of any wavelength may, when absorbed, become thermal energy and result in an increase in the temperature of the absorbing body.

Radiator. That which is capable of emitting energy in wave form.

Radioactive. The property of an isotope or element that is characterized by spontaneous decay to emit radiation.

Radioactivity. Emission of energy in the form of alpha-, beta-, or gamma-radiation from the nucleus of an atom. Always involves change of one kind of atom into a different kind. A few elements, such as radium, are naturally radioactive. Other radioactive forms are induced. See Radioisotope.

Radioactivity concentration guide (RCG). The concentration of radioactivity in the environment that is determined to result in organ doses equal to the radiation protection guide (RPG).

Radiochemical. Any compound or mixture containing a sufficient portion of radioactive elements to be detected by a Geiger counter.

Radiochemistry. The branch of chemistry concerned with the properties and behavior of radioactive materials.

Radiodiagnosis. A method of diagnosis that involves x-ray examination.

Radiohumeral joint. Part of the elbow. Not truly a joint, but a thrust bearing.

Radioisotope. A radioactive isotope of an element. A radioisotope can be produced by placing material in a nuclear reactor and bombarding it with neutrons. Many of the fission products are radioisotopes. Sometimes used as tracers, as energy sources for chemical processing or food pasteurization, or as heat sources for nuclear batteries. Radioisotopes are at present the most widely used outgrowth of atomic research and are one of the most important peacetime contributions of nuclear energy.

Radionuclide. A radioactive nuclide; one that has the capability of spontaneously emitting radiation.

Radioresistant. Relatively invulnerable to the effects of radiation.

Radiosensitive. Tissues that are more easily damaged by radiation.

Radiotherapy. Treatment of human ailments with the application of relatively high roentgen dosages.

Radium. One of the earliest-known naturally radioactive elements. It is far more radioactive than uranium and is found in the same ores.

Radius. The long bone of the forearm in line with the thumb; the active element in the forearm during pronation (inward rotation) and supination (outward rotation). Also provides the forearm connection to the wrist joint.

Radon progeny. Radioactive decay products of radon. See *daughter.*

Rale. Any abnormal sound or noise in the lungs.

Random noise. A sound or electrical wave whose instantaneous amplitudes occur as a function of time, according to a normal (Gaussian) distribution curve. Random noise is an oscillation whose instantaneous magnitude is not specified for any given instant of time. The instantaneous magnitudes of a random noise are specified only by probability functions giving the fraction of the total time that the magnitude, or some sequence of the magnitudes, lies within a specific range.

Rare earths. Originally, the elements in the periodic table with atomic numbers 57 through 71. Often included are numbers 39 and, less often, 21 and 90. Emerging uses include the manufacture of special steels and glasses.

Rash. Abnormal reddish coloring or blotch on some part of the skin.

Rated-line voltage. The range of potentials, in volts, of the supply line specified by the manufacturer at which an x-ray machine is designed to operate.

Rated output current. The maximum allowable lead current of an x-ray high-voltage generator.

Rated output voltage. The allowable peak potential, in volts, at the output terminals of an x-ray high-voltage generator.

Raynaud's syndrome or phenomenon. Abnormal constriction of the blood vessels of the fingers on exposure to cold temperature.

RBE. Relative biological effectiveness; the relative effectiveness of the same absorbed dose of two ionizing radiations in producing a measurable biological response.

Reactivity (chemical**).** A substance's susceptibility to undergo a chemical reaction or change that may result in dangerous side effects, such as an explosion, burning, and corrosive or toxic emissions.

Reactor. An atomic "furnace" or nuclear reactor. In a reactor, nuclei of the fuel undergo controlled fission under the influence of neutrons. The fission produces new neutrons in a chain reaction that releases large amounts of energy. This energy is removed as heat that can be used to make steam. The moderator for the first reactor was piled-up blocks of graphite. Thus, a nuclear reactor was formerly referred to as a pile. Reactors are usually classified now as research, test, process heat, and power, depending on their principal function. No workable design for a controlled fusion reactor has yet been devised.

Reagent. Any substance used in a chemical reaction to produce, measure, examine, or detect another substance.

REL. Recommended exposure limit. An exposure limit, generally a time-weighted average, to a substance; developed by NIOSH based on toxicological and industrial hygiene data.

Recoil energy. The energy emitted and shared by the reaction products when a nucleus undergoes a nuclear reaction such as fission or radioactive decay.

Reduction. Addition of one or more electrons to an atom through chemical change.

Refractories. A material exceptionally resistant to the action of heat and hence used for lining furnaces; examples are fire clay, magnesite, graphite, and silica.

Regenerative process. Replacement of damaged cells by new cells.

Regimen. A regulation of the mode of living, diet, sleep, exercise, and so on for a hygienic or therapeutic purpose; sometimes mistakenly called regime.

Reid method. Method of determining the vapor pressure of a volatile hydrocarbon by the *Standard Method of Test for Vapor Pressure of Petroleum Products, ASTM* D323.

Relative humidity. The ratio of the quantity of water vapor present in the air to the quantity that would saturate it at any specific temperature.

Reliability. The degree to which an instrument, component, or system retains its performance characteristics over a period of time.

Rem. Roentgen equivalent man; a radiation dose unit that equals the dose in rads multiplied by the appropriate value of relative biological effect or Quality Factor for the particular radiation.

Renal. Having to do with the kidneys.

Replication. A fold or folding back; the act or process of duplicating or reproducing something.

Resin. A solid or semisolid amorphous (noncrystalline) organic compound or mixture of such compounds with no definite melting point and no tendency to crystallize. May be of vegetable (gum arabic), animal (shellac), or synthetic (celluloid) origin. Some resins may be molded, cast, or extruded. Others are used as adhesives, in the treatment of textiles and paper, or as protective coatings.

Resistance. (1) Opposition to the flow of air, as through a canister, cartridge, particulate filter, or orifice. (2) A property of conductors, depending on their dimensions, material, and temperature, that determines the current produced by a given difference in electrical potential.

Resonance. Each object or volume of air resonates or strengthens a sound at one or more particular frequencies. The frequency depends on the size and construction of the object or air volume.

Respirable-size particulates. Particulates in a size range that permits them to penetrate deep into the lungs upon inhalation.

Respirator. A device to protect the wearer from inhalation of harmful contaminants.

Respiratory system. Consists of the nose, mouth, nasal passages, nasal pharynx, pharynx, larynx, trachea, bronchi, bronchioles, air sacs (alveoli) of the lungs, and muscles of respiration.

Reticle. A scale or grid or other pattern located in the focus of the eyepiece of a microscope.

Retina. The light-sensitive inner surface of the eye that receives and transmits images formed by the lens.

Retro- (prefix). Backward or behind.

Reverberatory furnace. A furnace in which heat is supplied by burning fuel in a space between the charge and the low roof.

Rheumatoid. Resembling rheumatism, a disease marked by inflammation of the connective tissue structures of the body, especially the membranous linings of the joints, and by pain in these parts; eventually the joints become stiff and deformed.

Rhin-, rhino- (prefix)**.** Pertaining to the nose.

Rhinitis. Inflammation of the mucous membrane lining in the nasal passages.

Rickettsia. Rod-shaped microorganisms characterized by growing within the cells of animals. These human pathogens are often carried by arthropods.

Riser. In metal casting, a channel in a mold to permit escape of gases.

Roasting of ores. A refining operation in which ore is heated to a high temperature, sometimes with catalytic agents, to drive off certain impurities; an example is the roasting of copper ore to remove sulfur.

Roentgen (R). A unit of radioactive dose or exposure. See Rad.

Roentgenogram. A film produced by exposing x-ray film to x rays.

Roentgenography. Photography by means of roentgen rays. Special techniques for roentgenography of different areas of the body have been given specific names.

Route of entry. A path by which chemicals can enter the body. There are three main routes of entry: inhalation, ingestion, and skin absorption.

Rosin. Specifically applies to the resin of the pine tree and chiefly derives from the manufacture of turpentine. Widely used in the manufacture of soap and flux.

Rotameter. A flow meter consisting of a precision-bored, tapered, transparent tube with a solid float inside.

Rotary kiln. Any of several types of kilns used to heat material, as in the portland cement industry.

Rouge. A finely powdered form of iron oxide used as a polishing agent.

RTECS. Registry of Toxic Effects of Chemical Substances.

S

SAE. Sampling and analytical error. The reason a particular sampling result may vary from the true value. Quantitative estimates of SAE are often used to develop a clear picture of the potential range of a given exposure.

Safety can. An approved container of not more than 5 gal (19 L) capacity having a spring-closing lid and spout cover and designed to safely relieve internal pressure when subjected to fire exposure.

Sagittal plane. A plane from back to front vertically dividing the body into the right and left portions. Important in anthropometric definitions. Midsagittal plane is a sagittal plane symmetrically dividing the body.

Salamander. A small furnace, usually cylindrical in shape, without grates.

Salivation. An excessive discharge of saliva; ptyalism.

Salmonella. A genus of gram-negative, rod-shaped pathogenic bacteria.

Salt. A product of the reaction between an acid and a base. Table salt, for example, is a compound of sodium and chlorine. It can be made by reacting sodium hydroxide with hydrochloric acid.

Sampling. The withdrawal or isolation of a fractional part of a whole. In air analysis, the separation of a portion of an ambient atmosphere with subsequent analysis to determine concentration.

Sandblasting. A process for cleaning metal castings and other surfaces with sand by a high-pressure airstream.

Sandhog. Any worker doing tunneling work requiring atmospheric pressure control.

Sanitize. To reduce the microbial flora in or on articles such as eating utensils to levels judged safe by public health authorities.

Saprophyte. An organism living on dead organic matter.

SAR. Specific absorption rate.

Sarcoma. Malignant tumors that arise in connective tissue.

Scattered radiation. Radiation that is scattered by interaction with objects or within tissue.

Scintillation counter. A device for counting atomic particles by means of the tiny flashes of light (scintillations) that particles produce when they strike certain crystals or liquids.

Scler- (prefix)**.** Hard, tough.

Sclera. The tough white outer coat of the eyeball.

Scleroderma. Hardening of the skin.

Sebum. Oily lubricating secretion of the sebaceous glands.

Scotoma. A blind or partially blind area in the visual field.

Sealed source. A radioactive source sealed in a container or having a bonded cover, in which the container or cover has sufficient mechanical strength to prevent contact with and dispersion of the radioactive material.

Sebaceous. Of, related to, or being fatty material.

Seborrhea. An oily skin condition caused by an excess output of sebum from the sebaceous glands of the skin.

SCBA. Self-contained breathing apparatus.

Semicircular canals. The special organs of balance closely associated with the hearing mechanism and the eighth cranial nerve.

Semiconductor or junction laser. A class of laser that normally produces relatively low CW power outputs; can be tuned in wavelength and has the greatest efficiency.

Sensation. The translation into consciousness of the effects of a stimulus exciting a sense organ.

Sensible. Capable of being perceived by the sense organs.

Sensitivity. The minimum amount of contaminant that can repeatedly be detected by an instrument.

Sensitization. The process of rendering an individual sensitive to the action of a chemical.

Sensitizer. A material that can cause an allergic reaction of the skin or respiratory system.

Sensorineural. Type of hearing loss that affects millions of people. If the inner ear is damaged, the hearing loss is sensory; if the fibers of the eighth nerve are affected, it is a neural hearing loss. Because the pattern of hearing loss is the same in either case, the term sensorineural is used.

Sensory end organs. Receptor organs of the sensory nerves located in the skin. Each end organ can sense only a specific type of stimulus. Primary stimuli are heat, cold, or pressure, each requiring different end organs.

Sensory feedback. Use of external signals perceived by sense organs to indicate quality or level of performance of an event triggered by voluntary action. On the basis of sensory feedback information, decisions may be made; for instance, permitting or not permitting an event to run its course or enhancing or decreasing activity levels.

Septum. A dividing wall or partition; used as a general term in anatomical nomenclature.

Septicemia. Blood poisoning; growth of infectious organisms in the blood.

Sequestrants. Chelates used to deactivate undesirable properties of metal ions without removing these ions from solution. Sequestrants have many uses, including application as antigumming agents in gasoline, antioxidants in rubber, and rancidity retardants in edible fats and oils.

Serum. (1) The clear fluid that separates from the blood during clotting. (2) Blood serum—containing antibodies.

Shakeout. In the foundry industry, the separation of the solid—but still not cold—casting from its molding sand.

Shale. Many meanings in industry, but in geology, a common fossil rock formed from clay, mud, or silt; somewhat stratified but without characteristic cleavage.

Shale oil. Tarry oil distilled from bituminous shale.

Shaver's disease. Bauxite pneumoconiosis.

Shell. The electrons around the nucleus of an atom are arranged in shells—spheres centered on the nucleus. The innermost shell is called K-shell, the next is called the L-shell, and so on to the Q-shell. The nucleus itself may also have a shell-type structure.

Shield, shielding. Interposed material (such as a wall) that protects workers from harmful radiations released by radioactive materials.

Shielded-metal arc welding (SMAW). An arc-welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

Shock. Primarily, the rapid fall in blood pressure following injury, operation, or the administration of anesthesia.

Short Term Exposure Limit (STEL). An airborne concentration of a substance to which workers are permitted to be exposed for a short duration, usually 15 minutes. The STEL is higher than that allowed by an 8 hour exposure limit. Like PELs, STELs are published and enforced by OSHA.

Shotblasting. A process for cleaning metal castings or other surfaces by small steel shot in a high-pressure airstream; a substitute for sandblasting to avoid silicosis.

SI. The *Système International d'Unités* (International System of Units), the metric system that is being adopted throughout the world. It is a modern version of the MKSA (meter, kilogram, second, ampere) system, whose details are published and controlled by an international treaty organization financed by member states of the Metre Convention, including the United States.

Siderosis. The deposition of iron pigments in the lung—can be associated with disease.

Sievert. Unit of absorbed radiation dose in Gray times the Quality Factor of the radiation in comparison to gamma-radiation. A Sievert equals 100 rem.

Silica gel. A regenerative absorbent consisting of amorphous silica manufactured by the action of HCl on sodium silicate. Hard, glossy, quartz-like in appearance. Used in dehydrating and drying and as a catalyst carrier.

Silicates. Compounds of silicon, oxygen, and one or more metals with or without hydrogen. These dusts cause nonspecific dust reactions, but generally do not interfere with pulmonary function or result in disability.

Silicon. A nonmetallic element being, next to oxygen, the chief elementary constituent of the earth's crust.

Silicones. Unique group of compounds made by molecular combination of silicon (or certain silicon compounds) with organic chemicals. Produced in a variety of forms, including silicone fluids, resins, and rubber. Silicones have special properties, such as water repellency, wide temperature resistance, high durability, and great dielectric strength.

Silicosis. A disease of the lungs caused by the inhalation of silica dust.

Silver solder. A solder of varying components but usually containing an appreciable amount of cadmium.

Simple tone (pure tone). (1) A sound wave whose instantaneous sound pressure is a simple sinusoidal function of time. (2) A sound sensation characterized by its singularity of pitch.

Sintering. Process of making coherent powder of earthy substances by heating without melting.

Skin dose. A special instance of tissue dose referring to the dose immediately on the surface of the skin.

Slag. The dross of flux and impurities that rise to the surface of molten metal during melting and refining.

Slot velocity. Linear flow rate through the opening in a slot-type hood (plating, degreasing operations, and so on).

Short-term exposure limit (STEL). ACGIH-recommended exposure limit. Maximum concentration to which workers can be exposed for a short period of time (15 min) only four times throughout the day with at least 1 h between exposures.

Sludge. Any muddy or slushy mass. Specifically, mud from a drill hole in boring, muddy sediment in the steam boiler, or precipitated solid matter arising from sewage treatment processes.

Slug. A fuel element for a nuclear reactor; a piece of fissionable material. Slugs in large reactors consist of uranium coated with aluminum to prevent corrosion.

Slurry. A thick, creamy liquid resulting from the mixing and grinding of limestone, clay, water, and other raw materials.

SMACNA. Sheet Metal and Air Conditioning National Association.

Smog. Irritating haze resulting from the sun's effect on certain pollutants in the air, notably automobile and industrial exhaust.

Smoke. An air suspension (aerosol) of particles originating from combustion or sublimation; generally contains droplets as well as dry particles. Tobacco, for instance, produces a wet smoke composed of minute tarry droplets.

Soap. Ordinarily a metal salt of a fatty acid, usually sodium stearate, sodium oleate, sodium palmitate, or some combination of these.

Soapstone. Complex silicate of varied composition, similar to some talcs, with wide industrial application, including rubber manufacture.

Solder. A material used for joining metal surfaces together by filling a joint or covering a junction. The most commonly used solder contains lead and tin; silver solder may contain cadmium. Zinc chloride and fluorides are commonly used as fluxes to clean the soldered surfaces.

Solid-state laser. A type of laser that uses a solid crystal such as ruby or glass; commonly used in pulsed lasers.

Solution. Mixture in which the components lose their individual properties and are uniformly dispersed. All solu-

tions are composed of a solvent (water or other fluid) and a solute (the dissolved substance). A true solution is homogeneous, as salt in water.

Solvent. A substance that dissolves another substance. Usually refers to organic solvents.

Soma. Body, as distinct from psyche (mind).

Somatic. Pertaining to all tissue other than reproductive cells.

Somatype. Somatotype. In anthropometry, a class of body build.

Somnolence. Sleepiness; also unnatural drowsiness.

Soot. Agglomerations of carbon particles impregnated with tar; formed in the incomplete combustion of carbonaceous material.

Sorbent. (1) A material that removes toxic gases and vapors from air inhaled through a canister or cartridge. (2) Material used to collect gases and vapors during air-sampling.

Sound. An oscillation in pressure, stress, particle displacement, particle velocity, and so on, propagated in an elastic material, in a medium with internal forces (elastic or viscous, for example); or, the superposition of such propagated oscillations. Also the sensation produced through the organs of hearing usually by vibrations transmitted in a material medium, commonly air.

Sound absorption. The change of sound energy into some other form, usually heat, on passing through a medium or striking a surface. Also, the property possessed by materials and objects, including air, of absorbing sound energy.

Sound absorption coefficient. The ratio of the sound energy absorbed by the surface of a medium (or material) exposed to a sound field (or to sound radiation) to the sound energy incident on that surface.

Sound analyzer. A device for measuring the band-pressure level or pressure-spectrum level of a sound as a function of frequency.

Sound level. A weighted sound-pressure level obtained by the use of metering characteristics and the weighting A, B, or C specified in ANSI S1.4.

Sound-level meter and octave-band analyzer. Instruments for measuring sound-pressure levels in decibels referenced to 0.0002 microbars. Readings can also be made in specific octave bands, usually beginning at 75 Hz and continuing through 10,000 Hz.

Sound-pressure level (SPL). The level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure, which must be explicitly stated.

Sound transmission. The word *sound* usually means sound waves traveling in air. However, sound waves also travel in solids and liquids. These sound waves may be transmitted to air to make sound we can hear.

Sound transmission loss. A barrier's ability to block transmission; measured in decibels.

Sour gas. Slang for either natural gas or a gasoline contaminated with odor-causing sulfur compounds. In natural gas, the contaminant is usually hydrogen sulfide; in gasoline, usually mercaptans.

Source. Any substance that emits radiation. Usually refers to a piece of radioactive material conveniently packaged for scientific or industrial use.

Spasm. Tightening or contraction of any set of muscles.

Specific Absorption (SA). Quantity of radiofrequency energy in joules per kilogram.

Specific Absorption Rate. Radiofrequency dosage term (rate at which energy is transferred to tissue) expressed as watts of power per kilogram of tissue.

Specific gravity. The ratio of the mass of a unit volume of a substance to the mass of the same volume of a standard substance at a standard temperature. Water at 39.2 F (4 C) is usually the standard for liquids; for gases, dry air (at the same temperature and pressure as the gas) is often taken as the standard substance. See Density.

Specific ionization. See Ionization.

Specific volume. The volume occupied by a unit mass of a substance under specified conditions of temperature and pressure.

Specific weight. The weight per unit volume of a substance; same as density.

Specificity. The degree to which an instrument or detection method is capable of accurately detecting or measuring the concentration of a single contaminant in the presence of other contaminants.

Spectrography—spectral emission. An instrumental method for detecting trace contaminants using a spectrum formed by exciting the subject contaminants by various means, causing characteristic radiation to be formed, which is dispersed by a grating or prism and photographed.

Spectrophotometer. A direct-reading instrument used for comparing the relative intensities of corresponding electromagnetic wavelengths produced by absorption of ultraviolet, visible, or infrared radiation from a vapor or gas.

Spectroscopy. Observation of the wavelength and intensity of light or other electromagnetic waves absorbed or emitted by various materials. When excited by an arc or spark, each element emits light of certain well-defined wavelengths.

Spectrum. The frequency distribution of the magnitudes (and sometimes phases) of the components of the wave. Also used to signify a continuous range of frequencies, usually wide in extent, within which waves have some specified common characteristics. Also, the pattern of red-to-blue light observed when a beam of sunlight passes through a prism and then projects upon a surface.

Specular reflections. Mirrorlike reflections that are important to minimize in laser work.

Speech interference level (SIL). The average, in decibels, of the sound-pressure levels of a noise in the three octave bands of frequency: 600–1,200, 1,200–2,400, and 2,400–4,800 Hz.

Speech perception test. A measurement of hearing acuity by the administration of a carefully controlled list of

words. The identification of correct responses is evaluated in terms of norms established by the average performance of normal listeners.

Speech reading. Lip reading or visual hearing.

Sphincter. A muscle that surrounds an orifice and functions to close it.

Sphygmomanometer. Apparatus for measuring blood pressure (and a good word for testing spelling ability).

Spore. A resistant body formed by certain microorganisms; resistant resting cells. Mold spores: unicellular reproductive bodies.

Spot size. Cross-sectional area of laser beam at the target.

Spot welding. One form of electrical-resistance welding in which the current and pressure are restricted to the spots of metal surfaces directly in contact.

Spray coating painting. The result of the application of a spray in painting as a substitute for brush painting or dipping.

Squamous. Covered with or consisting of scales.

Stain. A dye used to color microorganisms as an aid to visual inspection.

Stamping. A term with many different usages in industry; a common one is the crushing of ores by pulverizing.

Standard air. Air at standard temperature and pressure. The most common values are 70 F (21.1 C) and 29.92 in. Hg (101.3 kPa). Also, air with a density of 0.075 lb/ft^3 (1.2 kg/m^3) is substantially equivalent to dry air at 70 F and 29.92 in. Hg.

Standard air density. The density of air—0.075 lb/ft^3 (1.2 kg/m^3), at standard conditions.

Standard conditions. In industrial ventilation, 70 F (21.1 C), 50 percent relative humidity, and 29.92 in. Hg (101.3 kPa) atmospheric pressure.

Standard gravity. Standard accepted value for the force of gravity. It is equal to the force that produces an acceleration of 32.17 ft/s (9.8 m/s).

Standard Industrial Classification (SIC) Code. Classification system for places of employment according to major type of activity.

Standard temperature and pressure. See Standard air.

Standard Threshold Shift (STS). An average loss of hearing acuity in either ear of 10 dB as averaged over the 2,000-, 3,000- and 4,000-hertz frequencies.

Standing wave. A periodic wave having a fixed distribution in space that is the result of interference of progressive waves of the same frequency and kind. Such waves are characterized by the existence of nodes or partial nodes and antinodes that are fixed in space.

Stannosis. A form of pneumoconiosis caused by the inhalation of tin-bearing dusts.

Static pressure. The potential pressure exerted in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal (at right angles) to the direction of flow; thus it shows the tendency to burst or collapse the pipe. When added to velocity pressure, it gives total pressure.

Static pressure curve. A graphical representation of the volumetric output and fan static pressure relationship for a fan operating at a specific rotating speed.

Static pressure regain. The increase in static pressure in a system as air velocity decreases and velocity pressure is converted into static pressure according to Bernoulli's theorem.

STEL. See Short Term Exposure Limit.

Sterile. Free of living microorganisms.

Sterility. Inability to reproduce.

Sterilization. The process of making sterile; the killing of all forms of life.

Sterilize. To perform any act that results in the absence of all life on or in an object.

Sternomastoid muscles. A pair of muscles connecting the breastbone and lower skull behind the ears, which flex or rotate the head.

Stink damp. In mining, hydrogen sulfide.

Stp flow rate. The rate of flow of fluid, by volume, corrected to standard temperature and pressure.

Stp volume. The volume that a quantity of gas or air would occupy at standard temperature and pressure.

Stress. A physical, chemical, or emotional factor that causes bodily or mental tension and may be a factor in disease causation or fatigue.

Stressor. Any agent or thing causing a condition of stress.

Strip mine. A mine in which coal or ore is extracted from the earth's surface after removal of overlayers of soil, clay, and rock.

Stupor. Partial unconsciousness or nearly complete unconsciousness.

Sublimation. A process in which a material passes directly from a solid to a gaseous state and condenses to form solid crystals, without liquefying.

Sulcus (pl. sulci)**.** A groove, trench, or furrow; used in anatomical nomenclature as a general term to designate such a depression, especially on the surface of the brain, separating the gyri; also, a linear depression in the surface of a tooth, the sloping sides of which meet at an angle.

Supination. Rotation of the forearm about its own longitudinal axis. Supination turns the palm upward when the forearm is horizontal, and forward when the body is in anatomical position. Supination is an important element of available motions inventory for industrial application, particularly where tools such as screwdrivers are used. Efficiency in supination depends on arm position. Workplace design should provide for elbow flexion at 90 degrees.

Supra- (prefix)**.** Above, on.

Surface-active agent; surfactant. Any of a group of compounds added to a liquid to modify surface or interfacial tension. In synthetic detergents, which is the best known use of surface-active agents, reduction of interfacial tension provides cleansing action.

Surface coating. Paint, lacquer, varnish, or other chemical composition used for protecting and/or decorating surfaces. See Protective coating.

Suspect carcinogen. A material believed to be capable of causing cancer, based on limited scientific evidence.

Sweating. (1) Visible perspiration. (2) The process of uniting metal parts by heating solder so that it runs between the parts.

Swing grinder. A large power-driven grinding wheel mounted on a counterbalanced swivel-supported arm guided by two handles.

Symptom. Any bit of evidence from a patient indicating illness; the subjective feelings of the patient.

Syncope. Fainting spell.

Syndrome. A collection, constellation, or concurrence of signs and symptoms, usually of disease.

Synergism. Cooperative action of substances whose total effect is greater than the sum of their separate effects.

Synergistic. Pertaining to an action of two or more substances, organs, or organisms to achieve an effect greater than the additive effects of the separate elements.

Synonym. Another name by which a chemical may be known.

Synthesis. The reaction or series of reactions by which a complex compound is obtained from simpler compounds or elements.

Synthetic. (From the Greek word *synthetikos*, "that which is put together.") "Man-made 'synthetic' should not be thought of as a substitute for the natural," according to *Encyclopedia of the Chemical Process Industries*, which adds: "Synthetic chemicals are frequently more pure and uniform than those obtained naturally." A classic example is synthetic indigo.

Synthetic detergents. Chemically tailored cleaning agents soluble in water or other solvents. Originally developed as soap substitutes; because they do not form insoluble precipitates, they are especially valuable in hard water. They may be composed of surface-active agents alone, but generally are combinations of surface-active agents and other substances, such as complex phosphates, to enhance detergency.

Synthetic rubber. Artificial polymer with rubber-like properties. Types have varying composition and properties. Major types are designated as S-type, butyl, neoprene (chloroprene polymers), and N-type. Several synthetics duplicate the chemical structure of natural rubber.

Systemic. Spread throughout the body; affecting all body systems and organs, not localized in one spot or area.

T

Tachy- (prefix)**.** Indicates fast or speedy, as in *tachycardia*, abnormally rapid heartbeat.

Tailings. In mining or metal recovery processes, the gangue rock residue after all or most of the metal has been extracted.

Talc. A hydrous magnesium silicate used in ceramics, cosmetics, paint, and pharmaceuticals, and as a filler in soap, putty, and plaster.

Tall oil. (Derived from the Swedish word *tallolja*; a material first investigated in Sweden—not synonymous with U.S. pine oil.) Natural mixture of rosin acids, fatty acids, sterols, high-molecular weight alcohols, and other materials, derived primarily from waste liquors of sulfate wood pulp manufacture. Dark brown, viscous, oily liquid often called liquid rosin.

Tar. A loose term embracing wood, coal, or petroleum exudations. In general represents complex mixture of chemicals of top fractional distillation systems.

Tar crude. Organic raw material derived from distillation of coal tar and used for chemicals.

Tare. A deduction of weight, made in allowance for the weight of a container or medium. The initial weight of a filter, for example.

Target. The material into which the laser beam is fired or at which electrons are fired in an x-ray tube.

TEM. See Transmission Electron Microscopy.

Temper. To relieve the internal stresses in metal or glass and to increase ductility by heating the material to a point below its critical temperature and cooling slowly. See Anneal.

Temperature. The condition of a body that determines the transfer of heat to or from other bodies. Specifically, it is a manifestation of the average translational kinetic energy of the molecules of a substance caused by heat agitation. See Celsius and Kelvin scale.

Temperature, dry-bulb. The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

Temperature, effective. An arbitrary index that combines into a single value the effect of temperature, humidity, and air movement on the sensation of warmth or cold felt by the human body. The numerical value is the temperature of still, saturated air that would induce an identical sensation.

Temperature, mean radiant (MRT). The temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing nonuniform environment.

Temperature, wet-bulb. Thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer.

Tempering. The process of heating or cooling makeup air to the proper temperature.

Temporary threshold shift (TTS). The hearing loss suffered as the result of noise exposure, all or part of which is recovered during an arbitrary period of time when one is removed from the noise. It accounts for the necessity of checking hearing acuity at least 16 hours after a noise exposure.

Tendon. Fibrous component of a muscle. It often attaches to bone at the area of application of tensile force. When its cross section is small, stresses in the tendon are

high, particularly because the total force of many muscle fibers is applied at the single terminal tendon. See Tenosynovitis.

Tennis elbow. Sometimes called lateral epicondylitis, an inflammatory reaction of tissues in the lateral elbow region.

Tenosynovitis. Inflammation of the connective tissue sheath of a tendon.

Teratogen. An agent or substance that may cause physical defects in the developing embryo or fetus when a pregnant female is exposed to that substance.

Terminal velocity. The terminal rate of fall of a particle through a fluid as induced by gravity or other external force; the rate at which frictional drag balances the accelerating force (or the external force).

Tetanus. A disease of sudden onset caused by the toxin of the bacterium called *Clostridium tetani*. It is characterized by muscle spasms. Also called lockjaw.

Therm. A quantity of heat equivalent to 100,000 Btu.

Thermal pollution. Discharge of heat into bodies of water to the point that the increased warmth activates all sewage, depletes the oxygen the water must have to cleanse itself, and eventually destroys some of the fish and other organisms in the water. Eventually, thermal pollution makes the water smell and taste bad.

Thermonuclear reaction. A fusion reaction, that is, a reaction in which two light nuclei combine to form a heavier atom, releasing a large amount of energy. This is believed to be the sun's source of energy. It is called thermonuclear because it occurs only at a very high temperature.

Thermoplastic. Capable of being repeatedly softened by heat.

Thermoplastic plastics. Plastics that can repeatedly melt or that soften with heat and harden on cooling. Examples: vinyls, acrylics, and polyethylene.

Thermosetting. Capable of undergoing a chemical change from a soft to a hardened substance when heated.

Thermosetting plastics. Plastics that are heat-set in their final processing to a permanently hard state. Examples are phenolics, ureas, and melamines.

Thermostable. Resistant to changes by heat.

Thinner. A liquid used to increase the fluidity of paints, varnishes, and shellac.

Threshold. The level where the first effects occur; also, the point at which a person begins to notice a tone becoming audible.

Thromb- (prefix)**.** Pertaining to a blood clot.

Timbre. The quality given to a sound by its overtones; the tone distinctive of a singing voice or a musical instrument. Pronounced "TAMbra" or "TIMber."

Time-weighted average concentration (TWA). Refers to concentrations of airborne toxic materials weighted for a certain time duration, usually eight hours.

Tinning. Any work with tin such as tin roofing; in particular, in soldering, the primary coating with solder of the two surfaces to be united.

Tinnitus. A perception of sound arising in the head. Most often perceived as a ringing or hissing sound in the ears. Can be the result of high frequency hearing loss.

Tissue. A large group of similar cells bound together to form a structural component. An organ is composed of several kinds of tissue, and in this respect it differs from a tissue as a machine differs from its parts.

TLV.® Threshold Limit Value®. A time-weighted average concentration under which most people can work consistently for eight hours a day, day after day, with no harmful effects. A table of these values and accompanying precautions is published annually by the American Conference of Governmental Industrial Hygienists. See Appendix B.

Tolerance. (1) The ability of the living organism to resist the usually anticipated stress. (2) The limits of permissible inaccuracy in the fabrication of an article above and below its design specifications.

Tolerance dose. See Maximum permissible concentration and MPL.

Toluene, $C_6H_5CH_3$. Hydrocarbon derived mainly from petroleum but also from coal. Source of TNT, lacquers, saccharin, and many other chemicals.

Tone deafness. The inability to discriminate between fundamental tones close together in pitch.

Tonometer. Ophthalmic device used to measure eyeball pressure.

Topography. Configuration of a surface, including its relief and the position of its natural and man-made features.

Total pressure. The algebraic sum of the velocity pressure and the static pressure (with due regard to sign).

Toxemia. Poisoning by the way of the bloodstream.

Toxicant. A poison or poisonous agent.

Toxin. A poisonous substance derived from an organism.

Tracer. A radioisotope mixed with a stable material. The radioisotope enables scientists to trace the material as it undergoes chemical and physical changes. Tracers are used widely in science, industry, and agriculture today. When radioactive phosphorus, for example, is mixed with a chemical fertilizer, the radioactive substance can be traced through the plant as it grows.

Trachea. The windpipe, or tube that conducts air to and from the lungs. It extends between the larynx above and the point where it divides into two bronchi below.

Trade name. The commercial name or trademark by which a chemical is known. One chemical may have a variety of trade names depending on the manufacturing or distributors involved.

Transducer. Any device or element that converts an input signal into an output signal of a different form; examples include the microphone, phonograph pickup, loudspeaker, barometer, photoelectric cell, automobile horn, doorbell, and underwater sound transducer.

Transmission Electron Microscopy (TEM). A method of analyzing and quantifying samples for the presence of asbestos. Unlike light microscopy, TEM can definitively dis-

tinguish between asbestos fibers and other types of fibers. TEM also has a far higher resolution than light microscopy methods. However, since with TEM asbestos is quantified as number of structures rather than fibers per cubic centimeter, TEM results cannot be directly compared to the Permissible Exposure Limit of 0.1 fiber/cc.

Transmission loss. The ratio, expressed in decibels, of the sound energy incident on a structure to the sound energy that is transmitted. The term is applied both to building structures (walls, floors, etc.) and to air passages (muffler, ducts, etc.).

Transmutation. Any nuclear process that involves a change in energy or identity of the nucleus.

Transport (conveying) velocity. Minimum air velocity required to move the suspended particulates in the airstream.

Trauma. An injury or wound brought about by an outside force.

Tremor. Involuntary shaking, trembling, or quivering.

Triceps. The large muscle at the back of the upper arm that extends the forearm when contracted.

Tridymite. Vitreous, colorless form of free silica formed when quartz is heated to 1,598 F (870 C).

Trigger finger. Also known as snapping finger, a condition of partial obstruction in flexion or extension of a finger. Once past the point of obstruction, movement is eased. Caused by constriction of the tendon sheath.

Tripoli. Rottenstone. A porous, siliceous rock resulting from the decomposition of chert or siliceous limestone. Used as a base in soap and scouring powders, in metal polishing, as a filtering agent, and in wood and paint fillers. A cryptocrystalline form of free silica.

Tritium. Often called hydrogen-3, extra-heavy hydrogen whose nucleus contains two neutrons and one proton. It is three times as heavy as ordinary hydrogen and is radioactive.

Tuberculosis. A contagious disease caused by infection with the bacterium *Mycobacterium tuberculosis*. It usually affects the lung, but bone, lymph glands, and other tissues may be affected.

Tularemia. A bacterial infection of wild rodents, such as rabbits. It may be generalized or localized in the eyes, skin, lymph nodes, or respiratory tract. It can be transmitted to humans.

Tumbling. An industrial process, as in founding, in which small castings are cleaned by friction in a revolving drum (tumbling mill, tumbling barrel), which may contain sand, sawdust, stone, etc.

Turbid. Cloudy.

Turbidity. Cloudiness; disturbances of solids (sediment) in a solution, so that it is not clear.

Turbinates. A series of scroll-like bones in the nasal cavity that serves to increase the amount of tissue surface exposed in the nose, permitting incoming air to be moistened and warmed prior to reaching the lungs. Also called conchae.

Turbulence loss. The pressure or energy lost from a ventilation system through air turbulence.

Turning vanes. Curved pieces added to elbows or fan inlet boxes to direct air and so reduce turbulence losses.

TWA. Time-weighted average.

Tympanic cavity. Another name for the chamber of the middle ear.

U

UCL. Upper confidence limit.

Ulcer. The destruction of an area of skin or mucous membrane.

Ulceration. The formation or development of an ulcer.

Ulna. One of the two bones of the forearm. It forms the hinge joint at the elbow and does not rotate about its longitudinal axis. It terminates at the wrist on the same side as the little finger. Task design should not impose thrust loads through the ulna.

Ulnar deviation. A position of the hand in which the angle on the little finger side of the hand with the corresponding side of the forearm is decreased. Ulnar deviation is a poor working position for the hand and may cause nerve and tendon damage.

Ultrasonics. The technology of sound at frequencies above the audio range.

Ultraviolet. Wavelengths of the electromagnetic spectrum that are shorter than those of visible light and longer than x rays, 10^{-5} cm to 10^{-6} cm wavelength.

Unstable. Refers to all radioactive elements, because they emit particles and decay to form other elements.

Unstable (reactive) liquid. A liquid that in the pure state or as commercially produced or transported, vigorously polymerizes, decomposes, condenses, or becomes self-reactive under conditions of shocks, pressure, or temperature.

Upper confidence limit (UCL). In sampling analysis, a statistical procedure used to estimate the likelihood that a particular value is above the obtained value.

Upper explosive limit (UEL). The highest concentration (expressed as the percentage of vapor or gas in the air by volume) of a substance that will burn or explode when an ignition source is present.

Uranium. A heavy metal. The two principal isotopes of natural uranium are U-235 and U-238. U-235 has the only readily fissionable nucleus, which occurs in appreciable quantities in nature—hence its importance as nuclear fuel. Only one part in 140 of natural uranium is U-235. Highly toxic and a radiation hazard that requires special consideration.

Urethr-, urethro- (prefix)**.** Relating to the urethra, the canal leading from the bladder for discharge of urine.

Urticaria. Hives.

USC. United States Code. The official compilation of federal statutes. New editions are issued approximately every 6 years. Cumulative supplements are issued annually.

V

Vaccine. A suspension of disease-producing microorganisms modified by killing or attenuation so that it does not

cause disease and can facilitate the formation of antibodies upon inoculation into humans or animals.

Valence. A number indicating the capacity of an atom and certain groups of atoms to hold others in combination. The term also is used in more complex senses.

Valve (air oxygen). A device that controls the direction of air or fluid flow or the rate and pressure at which air or fluid is delivered, or both.

Vapor pressure. Pressure (measured in pounds per square inch absolute-psia) exerted by a vapor. If a vapor is kept in confinement over its liquid so that the vapor can accumulate above the liquid (the temperature being held constant), the vapor pressure approaches a fixed limit called the maximum (or saturated) vapor pressure, dependent only on the temperature and the liquid.

Vapors. The gaseous form of substances that are normally in the solid or liquid state (at room temperature and pressure). The vapor can be changed back to the solid or liquid state either by increasing the pressure or decreasing the temperature alone. Vapors also diffuse. Evaporation is the process by which a liquid is changed to the vapor state and mixed with the surrounding air. Solvents with low boiling points volatilize readily.

Vapor volume. The number of cubic feet of pure solvent vapor formed by the evaporation of one gallon of liquid at 75°F (24°C).

Vasoconstriction. Decrease in the cross-sectional area of blood vessels. This may result from contraction of a muscle layer within the walls of the vessels or may be the result of mechanical pressure. Reduction in blood flow results.

Vat dyes. Water-insoluble, complex coal tar dyes that can be chemically reduced in a heated solution to a soluble form that can impregnate fibers. Subsequent oxidation then produces insoluble color dyestuffs that are remarkably fast to washing, light, and chemicals.

Vector. (1) Term applied to an insect or any living carrier that transports a pathogenic microorganism from the sick to the well, inoculating the latter; the organism may or may not pass through any developmental cycle. (2) Any quantity (for example, velocity, mechanical force, electromotive force) having magnitude, direction, and sense that can be represented by a straight line of appropriate length and direction.

Velocity. A vector that specifies the time rate of change of displacement with respect to a reference.

Velocity, capture. The air velocity required to draw contaminants into the hood.

Velocity, face. The inward air velocity in the plane of openings into an enclosure.

Velocity pressure. The kinetic pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity. When added to static pressure, it gives total pressure.

Velometer. A device for measuring air velocity.

Vena contracta. The reduction in the diameter of a flowing airstream at hood entries and other locations.

Veni-, veno- (prefix). Relating to the veins.

Ventilation. One of the principal methods to control health hazards, may be defined as causing fresh air to circulate to replace foul air simultaneously removed.

Ventilation, dilution. Airflow designed to dilute contaminants to acceptable levels. Also called general ventilation.

Ventilation, local exhaust. Ventilation near the point of generation of a contaminant.

Ventilation, mechanical. Air movement caused by a fan or other air-moving device.

Ventilation, natural. Air movement caused by wind, temperature difference, or other nonmechanical factors.

Vermiculite. An expanded mica (hydrated magnesium-aluminum-iron silicate) used in lightweight aggregates, insulation, fertilizer, and soil conditioners; as a filler in rubber and paints; and as a catalyst carrier.

Vertigo. Dizziness; more exactly, the sensation that the environment is revolving around you.

Vesicant. Anything that produces blisters on the skin.

Vesicle. A small blister on the skin.

Vestibular. Relating to the cavity at the entrance to the semicircular canals of the inner ears.

Viable. Living.

Vibration. An oscillation motion about an equilibrium position produced by a disturbing force.

Vinyl. A general term applied to a class of resins such as polyvinyl chloride, acetate, butyryl, etc.

Virulence. The capacity of a microorganism to produce disease.

Virulent. Extremely poisonous or venomous; capable of overcoming bodily defensive mechanisms.

Viruses. A group of pathogens consisting mostly of nucleic acids and lacking cellular structure.

Viscera. Internal organs of the abdomen.

Viscose. Term applied to viscous liquid composed of cellulose xanthate.

Viscose rayon. The type of rayon produced from the reaction of carbon disulfide with cellulose and the hardening of the resulting viscous fluid by passing it through dilute sulfuric acid, this final operation causing the evolution of hydrogen sulfide gas.

Viscosity. The property of a fluid that resists internal flow by releasing counteracting forces.

Viscosity, absolute. A measure of a fluid's tendency to resist flow, without regard to density. The product of a fluid's kinematic viscosity times its density, expressed in dyne-seconds per centimeter or poises (or pascal-seconds).

Viscosity, kinematic. The relative tendency of a fluid to resist flow. The value of the kinematic viscosity is equal to the absolute viscosity of the fluid divided by the fluid density and is expressed in units of stoke (or square meters per second).

Visible radiation. The wavelengths of the electromagnetic spectrum between 10^{-4} cm and 10^{-5} cm.

Vision, photopic. Vision attributed to cone function characterized by the ability to discriminate colors and small details; daylight vision.

Vision, scotopic. Vision attributed to rod function characterized by the lack of ability to discriminate colors and small details and effective primarily in the detection of movement and low luminous intensities; night vision.

Visual acuity. Ability of the eye to sharply perceive the shapes of objects in the direct line of vision.

Vitreous humor. Jellylike fluid behind the lens of the eye.

Volatility. The tendency or ability of a liquid to vaporize. Such liquids as alcohol and gasoline, because of their well-known tendency to evaporate rapidly, are called volatile liquids.

Volume flow rate. The quantity (measured in units of volume) of a fluid flowing per unit of time, such as cubic feet per minute, gallons per hour, or cubic meters per second.

Volume, specific. The volume occupied by one pound of a substance under specified conditions of temperature and pressure.

Volumetric analysis. A statement of the various components of a substance (usually applied to gases only), expressed in percentages by volume.

Vulcanization. The process of combining rubber (natural, synthetic, or latex) with sulfur and accelerators in the presence of zinc oxide under heat and usually pressure in order to change the material permanently, from a thermoplastic to a thermosetting composition, or from a plastic to an elastic condition. Strength, elasticity, and abrasion resistance also are improved.

Vulcanizer. A machine in which raw rubber that has been mixed with chemicals is cured by heat and pressure to render it less plastic and more durable.

W

WAN. Wide-area network of linked computers or LANs, whose elements are usually geographically distant.

Wart. A characteristic growth on the skin, appearing most often on the fingers; generally regarded as a result of a virus infection. Synonym: verruca.

Water column. A unit used in measuring pressure. See also Inches of water column.

Water curtain or waterfall booth. A term with many different meanings in industry; but in spray painting, a stream of water running down a wall into which the excess paint spray is drawn or blown by fans, and which carries the paint downward to a collecting point.

Waterproofing agents. Usually formulations of three distinct materials: a coating material, a solvent, and a plasticizer. Among the materials used in waterproofing are cellulose esters and ether, polyvinyl chloride resins or acetates, and variations of vinyl chloride-vinylidine chloride polymers.

Watt (W). A unit of power equal to one joule per second. See Erg.

Watts/cm^2. A unit of power density used in measuring the amount of power per area of absorbing surface, or per area of a CW laser beam.

Wavelength. The distance in the line of advance of a wave from any point to a like point on the next wave. It is usually measured in angstroms, microns, or nanometers.

Weight. The force with which a body is attracted toward the earth. Although the weight of a body varies with its location, the weights of various standards of mass are often used as units of force. See Force.

Weighting network (sound**).** Electrical networks (A, B, C) associated with sound level meters. The C network provides a flat response over the frequency range 20–10,000 Hz; the B and A networks selectively discriminate against low (less than 1 kHz) frequencies.

Weld. A localized coalescence of metals or nonmetals produced either by heating the materials to suitable temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler material.

Welding. The several types of welding are electric arc-welding, oxyacetylene welding, spot welding, and inert or shielded gas welding using helium or argon. The hazards involved in welding stem from the fumes from the weld metal such as lead or cadmium metal, the gases created by the process, and the fumes or gases arising from the flux.

Welding rod. A rod or heavy wire that is melted and fused to metals in arc-welding.

Wet-bulb globe temperature index. An index of the heat stress in humans when work is being performed in a hot environment.

Wet-bulb temperature. Temperature as determined by the wet-bulb thermometer or a standard sling psychrometer or its equivalent. This temperature is influenced by the evaporation rate of the water, which in turn depends on the humidity (amount of water vapor) in the air.

Wet-bulb thermometer. A thermometer having the bulb covered with a cloth saturated with water.

Wheatstone bridge. A type of electrical circuit used in one type of combustible gas monitor. Combustion of small quantities of the ambient gas are detected as changes in electrical resistivity by this circuitry.

White damp. In mining, carbon monoxide.

White noise. A noise whose spectrum density (or spectrum level) is substantially independent of frequency over a specified range.

Wide band. Applied to a wide band of transmitted waves, with neither of the critical or cutoff frequencies of the filter being zero or infinite.

Work. When a force acts against resistance to produce motion in a body, the force is said to do work. Work is measured by the product of the force acting and the distance moved against the resistance. The units of measurement are the erg (a joule is 1×10^7 ergs) and the foot-pound.

Work hardening. The property of metal to become harder and more brittle on being worked (bent repeatedly or drawn).

Work strain. The natural physiological response of the body to the application of work stress. The locus of the reaction may be remote from the point of application of work stress. Work strain is not necessarily traumatic but may appear as trauma when excessive, either directly or cumulatively, and must be considered by the industrial engineer in equipment and task design.

Work stress. Biomechanically, any external force acting on the body during the performance of a task. It always produces work strain. Application of work stress to the human body is the inevitable consequence of performance of any task, and is therefore synonymous with stressful work conditions only when excessive. Work stress analysis is an integral part of task design.

Working level (WL). Any combination of radon daughters in one liter of air that result in the ultimate emission of 1.3×10^5 MeV of alpha energy.

X

Xanth- (prefix)**.** Yellow.

Xero- (prefix)**.** Indicated dryness, as in *xerostomia*, dryness of the mouth.

Xeroderma. Dry skin; may be rough as well as dry.

X rays. Highly penetrating radiation similar to gamma-rays. Unlike gamma-rays, x rays do not come from the nucleus of the atom but from the surrounding electrons. They are produced by electron bombardment. When these rays pass through an object, they give a shadow picture of the denser portions.

X-ray diffraction. Because all crystals act as three-dimensional gratings for x rays, the pattern of diffracted rays is characteristic for each crystalline material. This method is of particular value in determining the presence or absence of crystalline silica in an industrial dust.

X-ray tube. Any electron tube designed for the conversion of electrical energy into x-ray energy.

Z

Z. Symbol for atomic number. An element's atomic number is the same as the number of protons found in one of its nuclei. All isotopes of a given element have the same Z number.

Zinc protoporphyrin (ZPP). Hematopoietic enzyme used as a measure of recent lead exposure.

Zoonoses. Diseases biologically adapted to and normally found in lower animals, but that under some conditions also infect humans.

Zygote. Cell produced by the joining of two gametes (sex or germ cells).

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