PRINCIPLES OF

OCCUPATIONAL HEALTH & HYGIENE

PRINCIPLES OF OCCUPATIONAL HEALTH & HYGIENE

An introduction

EDITED BY CHERILYN TILLMAN

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Foreword

In Greek mythology, Asclepius, son of Apollo and Coronis, was fostered to the centaur Chiron. Chiron taught Asclepius the arts of healing and surgery. As the god of medicine, Asclepius was the father of six daughters, including Panacea, the goddess of healing and cures, assisted by her sisters Isso, Aceso and Aglaea. The incestuous union of Asclepius and Panacea yielded Hygieia. Hygieia was the goddess associated with maintenance of good health and the prevention of disease. Her symbol, a snake drinking from a jar she carried, is combined with Asclepius' staff as the symbol of the medical profession.

Occupational and industrial hygiene has been variously described by professional and government organisations, teaching institutions and consultants, but all definitions include the recognition and prevention of disease in workplaces. For example, the International Occupational Hygiene Association* states:

> Occupational Hygiene is the discipline of anticipating, recognising, evaluating and controlling health hazards in the working environment with the objective of protecting worker health and well-being and safeguarding the community at large.

The term 'stressors' rather than 'hazards' is used by the Australian Institute of Occupational Hygienists:

> Occupational Hygiene is generally defined as the art and science dedicated to the Anticipation, Recognition, Evaluation, Communication and Control of environmental stressors in, or arising from, the work place that may result in injury, illness, impairment, or affect the well-being of workers and members of the community. These stressors are normally divided into the categories Biological, Chemical, Physical, Ergonomic and Psychosocial.

Nowadays, the term 'hygiene' is often associated in lay terms with cleanliness and sanitation. To be described as a hygienist is not usually an indication that disease prevention is the major goal. This gradual change in idiom may influence the public perception of our profession, resulting in a misunderstanding of our professional roles and capabilities, and a lack of appreciation of occupational hygiene as a career path.

This book may go some way to highlight the breadth and depth of occupational hygiene, and to promote the extensive capabilities of hygienists. It is targeted toward not only those being educated and trained in occupational hygiene but also toward practising hygienists who will use it as a desk reference source. It may also be useful to other practitioners in medicine, nursing, toxicology, epidemiology and other professional groups, to demonstrate areas in which collaboration with and support of hygienists may be advantageous. The mythical origins of Hygieia demonstrate the close—one may say intimate—links between professional disciplines in medicine and allied health, whose interactions may not be as close as that which bore Hygieia herself, but certainly reveal a family history of our aims in disease prevention.

John Edwards
AIOH President, 2006

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* The AIOH is a professional organisation representing the interests of private and governmental practitioners, educators, and others whose expertise is in the evaluation and control of workplace hazards and risks. It supports training and continuing professional education programs, as well as scientific meetings to promote the practice and development of the discipline of occupational hygiene. Further information may be obtained from <www.aioh.org.au>.

Preface

This book represents the most important project ever undertaken by the Australian Institute of Occupational Hygienists (AIOH). The book owes its origins to one of our members, Dr David Grantham, who is a Fellow of the AIOH and the author of Chapter 1.

In 1992 David authored and published a book titled *Occupational Health & Hygiene, Guidebook for the WHSO.* This book was written in response to the requirement in the *Queensland Workplace Health and Safety Act 1989–1990* for employers to appoint Workplace Health and Safety Officers (WHSOs). David perceived the need for a book to provide WHSOs with basic knowledge in matters of occupational health and hygiene as there were no adequate texts written with the Australian workplace in mind.

In 2002 David very generously handed over copyright of his book to the AIOH. The AIOH recognised that the book was in need of revision and so in 2003 embarked upon the ambitious project to revise and expand David's book. The intent was to produce a book that would be useful to a wider audience of health and safety practitioners and that would cover a larger number of topics, particularly topics which had emerged or grown in importance since the publication of David's book in 1992.

All the authors of the revised book are members of the AIOH who have written their chapters in their own time, without payment or favour, to support the AIOH in furthering the profession of occupational hygiene.

We hope that this book will prove to be a valuable resource to all occupational health and safety professionals. However it is also expected to find use as a textbook for tertiary and vocational courses in occupational health and safety (OH&S). It is targeted to the Australian market in that it refers to Australian Standards and exposure standards and, unlike similar books produced in northern hemisphere countries, it addresses specific issues seen in Australian workplaces; for example, its coverage of extremes of temperature focuses on heat rather than cold. It is therefore anticipated that this book will be useful to OH&S professionals and students in Asia, Africa and the Pacific, particularly in English-speaking countries and territories such as South Africa, Singapore, Hong Kong and New Zealand.

The project to produce this book has spanned almost 3 years and has had the involvement and support of many AIOH office bearers. In particular, the two people who held the position of Honorary Secretary of the AIOH during this time, Jen Hines and Linda Apthorpe, have provided invaluable support and encouragement to me in my role as Editor.

There are 18 authors who have worked tirelessly and with only an occasional protest to produce quality content for this book, and I and the Council of the AIOH thank them all for their attention to detail and professionalism and for working co-operatively with me during the gestation of this book.

I can speak for all the authors, as well as the AIOH, in thanking David Grantham for his interest, encouragement and assistance in updating and expanding his original material.

The AIOH is also grateful to those Full and Fellow members who volunteered to peer review chapters of the book, namely: Terry Gorman MAIOH (Chapter 1), Clive Paige MAIOH (Chapter 2), Dr David Grantham FAIOH (Chapter 3), Ron Capil MAIOH and Peter Knott MAIOH (Chapter 4), Ian Firth MAIOH (Chapter 5), Robert Golec MAIOH (Chapter 6), Dr Ian Grayson MAIOH (Chapter 7), Denise Elson MAIOH (Chapter 8), Martin Jennings FAIOH and Phillip Turner MAIOH (Chapter 9), Gary Foster MAIOH (Chapter 10), Dr Geza Benke FAIOH (Chapter 11), Jeff Parsons MAIOH (Chapter 12), Georgia Sinclair MAIOH (Chapter 13) and Dr David Bromwich FAIOH (Chapter 14).

The work of three members (Dr Deborah Glass MAIOH, Dr John Edwards MAIOH and Dr Dino Pisaniello FAIOH) in conducting a final style review of all chapters is also gratefully acknowledged.

I would like to thank the AIOH for offering me the position of Editor for this book. It was an honour to be entrusted with delivery of this important project.

Finally I would like to thank my husband, Tam, for his patience, understanding and support during this project, which consumed much more of our life and recreational time than I had ever envisaged when I was appointed to the position of Editor.

Dr Cherilyn Tillman
Editor
Melbourne, 2006

Author biographies

Editor
Cherilyn Tillman has a BSc (Physics) and MAppSc in Occupational Hazard Management, a PhD (Engineering), and is a Fellow of the AIOH as well as being a Certified Occupational Hygienist (COH). She has over 30 years' experience in occupational hygiene, occupational health and safety, risk management and risk engineering. She has worked in Sweden where she represented Sweden on a number of international committees and on working parties on sampling and analysis of asbestos and synthetic mineral fibres. Her work in occupational hygiene has involved workplace environment assessment (dust, noise, etc.) in manufacturing, research and mining environments. She is currently OHS Team Leader with the Victorian Employers' Chamber of Commerce and Industry.

Chapter 1
David Grantham, a Senior Principal Health Adviser with Workplace Health and Safety Queensland, holds degrees in science (chemistry) and economics as well as a PhD in environmental and occupational hygiene. He is a COH and Fellow of the AIOH. He has worked in governmental occupational hygiene for over 35 years investigating hygiene in factories, mines, workshops, laboratories, schools, tertiary institutions, hospitals, on farms and in offices. Having been exposed during that work to asbestos, coal and silica dusts, solvent vapours, exhaust gases, metal fumes, isocyanates, pesticides, explosives, exhaust gases, sterilants, fumigants, noise and heat, he has an interest in remaining healthy on the job and encouraging others to do likewise.

Chapter 2
John Edwards: for biographical details, refer to the entry for Chapter 8.

Geza Benke has a BSc (Physics), MAppSc (Environmental Engineering) and a PhD (Epidemiology), and is a Fellow of the AIOH as well as being a COH. He worked with the Victorian Environment Protection Authority for 5 years before joining the Victorian state government Occupational Hygiene Branch headed by the late Pam deSilva in 1985. His work in occupational hygiene mainly involved noise assessment and control, radiation safety and asbestos work. Since 1994 Geza has undertaken research in a range of occupational and environmental epidemiology studies. He is currently Senior Research Fellow with the Centre for Occupational and

Environmental Health, Department of Epidemiology and Preventive Medicine, Monash University.

Chapter 3

Ian Grayson's qualifications include a PhD in Chemistry and a Graduate Diploma in Occupational Hygiene. He is a Full Member of the AIOH as well as being a COH, and is also a Member of the American Conference of Governmental Industrial Hygienists (ACGIH®). Ian has over 20 years' experience as a Victorian government occupational hygienist and has extensive practical experience in the identification, assessment and control of chemical and physical hazards in a broad range of Victorian workplaces. Currently, Ian is a Senior Occupational Hygienist with WorkSafe Victoria.

Chapter 4

Garry Gately has a Diploma of Applied Chemistry and MChem in Analytical Chemistry and is a Fellow of the AIOH, as well as being a COH in Australia and a Certified Industrial Hygienist (CIH) in the United States. He has over 30 years' experience, of which more than 25 years has been in occupational health and safety. As the Corporate Hygienist for Orica (and formerly ICI Australia and ICI plc) he has had experience in many industrial sectors. He is currently the Corporate Lead SH&E Auditor for Orica.

David Bromwich has an honours degree in physics, masters degrees in medical physics and occupational hygiene and a research PhD. He is a Fellow of the AIOH, Full Member of the Australasian Radiation Protection Society (ARPS) and is a COH in Australia and CIH in the USA. He has over 30 years' experience in clinical biochemistry, health physics (uranium mining) and occupational hygiene and is currently senior lecturer in occupational hygiene at the School of Engineering in the Environmental Engineering Group at Griffith University in Brisbane. His research interests are chemical protective clothing, industrial ventilation and exposure visualisation.

Chapter 5

Geoff Pickford has a BE (Mech) and MEngSc in fluid mechanics, acoustics and advanced heat transfer, and is a Fellow of the AIOH as well as being a COH and CIH. He has 34 years' occupational hygiene experience, the past 18 years as a consultant, currently with Pickford & Ryder Consulting Pty Ltd. His voluntary work in occupational hygiene has included drafting analytical methods for the National Health and Medical Research Council, National Occupational Health and Safety Commission and Australian Standards, as well as technical assistance to the National Association of Testing Authorities in relation to assessment policies and proficiency testing programs.

Brian Davies has been associated with the underground coal mining industry all his life. His interest in diesel particulate began in 1988 in his role as Chief Occupational Hygienist for BHP Co Ltd, and he has been an active researcher in the field since 1990, completing his PhD on the subject in 2004. Brian was awarded the 2002

Yant Award by the American Industrial Hygiene Association and was the first non-American to receive the William Steiger Award from the American Conference of Governmental Industrial Hygienists in 2003. In 2005 Brian was honoured as a Member of the Order of Australia for his contributions to the health of coal miners and for his contributions to the AIOH.

Chapter 6

Ian Firth has a BSc (Hons) in zoology and MSc in Applied Biology (toxicology), and is a Full Member of the AIOH as well as being a COH. He has over 25 years' experience, one-third of it in environmental sciences and the rest in occupational hygiene. His environmental work has principally involved research on freshwater animal toxicology, environmental management and acid rock drainage management. His occupational hygiene work has involved workplace environment assessment (dust, noise, etc.) in hard rock mining settings in Papua New Guinea and Indonesia, and in smelting in the zinc/lead and aluminium industries. He is currently Principal Adviser—Occupational Health with Rio Tinto.

Chapter 7

Noel Tresider has Associate Diplomas in Applied Chemistry and Chemical Engineering. He is a Fellow of the AIOH and is a COH and CIH. He has over 40 years' experience in the oil and chemical industries. He worked for Mobil Oil Australia as Industrial Hygiene Advisor and product safety specialist, and also provided industrial hygiene services to Mobil affiliates in New Zealand, Micronesia, Malaysia and Hong Kong. More recently he has provided industrial hygiene services to other major oil companies in Victoria, and also to small business and tertiary institutes. He is now employed as the Chemical Project Officer at Baker Heart Research Institute in Melbourne.

Chapter 8

John Edwards is Associate Professor in Occupational and Environmental Health at Flinders University. He is both a COH and an internationally accredited toxicologist (UK and European Registers of Toxicologists). His research interests include biological and biological-effect monitoring of a variety of chemicals including solvents, pesticides and carcinogens. He has extensive consulting experience in combining occupational hygiene with occupational toxicology and in particular in human health risk assessments.

Chapter 9

Stephen (Steve) Brown started his career as a polymer chemist with a BAppSc (Hons) in industrial chemistry, and MAppSc in fracture mechanisms. He undertook a Graduate Diploma in Occupational Hygiene in 1982 and became a Full Member of the AIOH, later becoming a COH. He was CSIRO Project Leader for Indoor Air Quality from 1992 to 2000, and led or participated in several national/international projects dealing with asbestos control, guidelines for indoor air quality, standards development, building assessments, pollutant emissions research and car suicide prevention. In 2000, he completed a PhD thesis on indoor air pollution by volatile organic compounds from building materials. He was Principal Research Scientist/Project Leader—Air Quality Sciences at CSIRO until he resigned in 2006 to become a part-time researcher.

Chapter 10

Beno Groothoff has a background in mechanical engineering and an MSc in Public Health (Occupational Health and Safety). He is a Full Member of the AIOH as well as being a COH. He has 35 years' experience, one-third of it in environmental pollution control and the rest in occupational hygiene. His environmental work has principally involved environmental management by containing the effects of industries. His occupational hygiene work has involved workplace environment assessment (dust, noise, vibration, radiation etc.) in a large variety of industries in both Holland and Queensland. He is currently Principal Adviser (Noise and Vibration) with the Occupational Health Unit of Workplace Health and Safety Queensland.

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Chapter 12

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Martin Jennings is an occupational hygienist with over 25 years' experience in government, the defence, and nuclear and chemical industries. His qualifications include a BSc, a Masters degree in Occupational Hygiene and a further Masters degree in Administration. He is a COH and CIH in Australia and the United States and is a Fellow of the AIOH.

Chapter 13

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Chapter 14

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1. The hazardous work environment:

THE HYGIENE CHALLENGE

Dr David Grantham FAIOH

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1.1 INTRODUCTION

Occupational hygiene can be considered as the fundamental process skill required to achieve good health outcomes in workplaces where there are chemical, biological and physical agents. This chapter commences by showing how difficult it often is to recognise hazards to health in workplaces and how difficult it has been historically to control workplace conditions to achieve acceptable health outcomes, even when the problems are identified. Some common examples from everyday workplaces and historical events, both national and international, demonstrate the extent of these problems with some classic occupational health hazards. An overview of occupational hygiene is then introduced, together with the walkthrough survey and a flowchart showing the scope of hygiene investigations. This chapter also lays out the framework for considering all the topics developed in the following chapters.

Lastly, this chapter introduces the reader to the complementary approach of control banding. Control banding, which focuses on exposure controls, has evolved to simplify the task of identifying suitable controls when no information about occupational exposure levels is available or when appropriate skills or resources are unavailable to pursue conventional hygiene processes.

1.2 HISTORICAL BACKGROUND

Today's workplaces are full of materials and processes which are potentially hazardous to health. Industry depends on a large range of naturally occurring and synthetic materials, many of which can adversely affect the health of workers handling them if they are excessively exposed.

The histories of many trades and workplaces have included traumatic injury, disease and death. The industrial revolution changed the fortune of the worker from one of agrarian poverty to one of working in new trades created with little or no understanding of the hazards they imposed. Mining the coal needed to fuel the steam-powered factories under primitive conditions produced accidents and fatalities on an unprecedented scale. Many of those who survived injury or escaped death became ill from dust diseases. In the mines, mills and factories, inexperienced workers, including children as young as 6 years, faced injury or death from machinery which was designed for output, not safety.

The pace of control of workplaces has been comparatively slow. Despite the perils of industrial life of the late 18th and early 19th centuries, it was not until 1833 that the first real labour laws and the Factory Inspectorate were established in the United Kingdom.

Some factory and mill owners operated exemplary establishments which took account of the general safety and health and welfare needs of their workers, but these were in the minority. With the development of chemical-based industries through the latter part of the 19th and early 20th centuries, many new occupational diseases emerged, some of which continued unchecked until more recent times. This was despite readily available evidence of the hazards. Occupational diseases such as those of miners (pneumoconiosis or dust diseases), fur carroters (mercurialism) and chimney sweeps (scrotal cancer) became accepted as part of the workplace landscape. It was not until relatively recent times, following the First World War, that significant technical and medical resources became available and were brought to bear on a wide range of occupational diseases. Workplace legislation has been slow to catch up with the identification of occupational health hazards.

1.3 THE PRESENT

Society does not expect workers to trade away their health and safety just to have a job. But occupationally-related illness can still occur in many workplaces, and not just in industrial workplaces. Chemicals which are potentially capable of causing cancer, lung diseases, blood and bone disorders, loss of mental ability, central nervous system debilitation, infertility and death are still found in factories and farms. Microbiological hazards coexist with humans and contribute to poor indoor air quality, or present significant risk of infectious diseases in animal handling, childcare, nursing and hospital care or community services where accidental body fluid exchange can occur. Industrial workplaces can also put physical and mental strains on the worker—for example, manual handling, noise, vibration, extremes of heat and cold and exposure to both ionising and non-ionising radiation. Humans have no natural protection against extreme exposures to any of these. All of these hazards contribute to make many workplaces potentially unhealthy.

Some of the occupationally-related disease appearing now is a legacy of former inaction. However, new cases of occupational ill health occur because of failure to implement known and often simple control techniques. The body of knowledge on common hazards in the workplace is now extensive and ignorance is rarely a plausible excuse for lack of control.

The following examples illustrate some **commonly recognised hazards**:

- repairing radiators with leaded solder
- welding, which produces gases and metal fume
- vehicle exhaust emissions, which produce carbon monoxide
- excessive ultraviolet radiation exposure from working outdoors
- agricultural use of pesticides and herbicides
- machinery which is noisy and vibrating
- quarry crushers producing dust.

In each of these cases, the hazard is usually recognised. For example, most people know that lead can be poisonous, that car exhaust fumes are dangerous, that pesticides can be harmful to humans as well as pests, and so on. What remains unrecognised is the extent to which a worker's health can be jeopardised.

Some **less commonly recognised hazards** occur with:

- photocopiers producing ozone
- use of chemicals for sterilising in hospitals
- non-ionising radiant energy from radio-frequency furnaces and heaters

- ‘sick’ air-conditioned buildings
- legionnaire’s disease.

In these cases, the hazard and the exposure may go unrecognised by both employer and worker.

While employers in Australia have the primary responsibility for implementing safer working practices, government has the task of providing guidelines through appropriate laws, practical regulations and codes of practice. Early efforts by legislators and employers were often ineffectual, although there have been some spectacular successes. For example, the prevalence of coalworkers’ pneumoconiosis, which had been as high as 27 per cent of workers in Australia before the Second World War (Moore & Badham 1931), and 16 per cent in 1948 (Glick 1968), had been reduced to virtually nonexistent levels by the turn of the 21st century due to the concerted long-term application of dust control through ventilation.

Throughout Australia (as in much of the industrialised world), the states and territories have introduced modern occupational health and safety laws and regulations intended to promote acceptable, achievable and enforceable programs which will usher in the required changes. Professional Health and Safety practitioners (H&S practitioners) now play a vital role in ensuring that good guidance is provided to employers in managing the risks from health hazards in the workplace. However, the task is not just as simple as ‘providing good guidance’. How does the H&S practitioner provide the proper guidance for something which cannot be seen, sometimes cannot be smelt, or cannot be sensed in the workplace—in other words, where the causal factors of disease can be far from obvious?

1.4 THE SERIOUS PROBLEM OF UNDERESTIMATION OF OCCUPATIONALLY RELATED DISEASE

Is work-related ill health important enough to deserve the attention it now receives? The last two decades in Australia have witnessed extensive expansion in occupational health laws and regulations, expanded government administration and new health-based inspectorates. There are mountains of technical guidance, numerous training programs, expanded legal services and growth in occupational health and safety professions and research programs. Where could evidence be found that chemicals or ‘hazardous substances’ really are detrimental to health? There are relatively few ill people in each workplace, but therein lies part of the answer. When disasters like mass drownings, a rail crash or an explosion occur, it is easy to count the bodies. In contrast, occupational disease resulting from exposure to a hazardous substance or a damaging physical agent (such as noise or radiation) often goes unrecognised, and thus the problem is underestimated. Because it can take a long time for occupational diseases to develop, the cause of such a disease is often not immediately apparent. Workers move away or change jobs or retire. A sick worker’s doctor may simply be unaware of the kind of work that a patient does or has done in the past. Historical records of occupational exposures are infrequent, although the new laws now mandate maintenance of some exposure records.

Reliable data on the contributions of the workplace to ill health in the community have traditionally been difficult to assemble, and this is a worldwide problem. Compensation data regarding work-related ill health under-represents the prevalence of work-related ill health. However, the greatest proportions of work-related cases of ill health have not been the result of traumatic accidents (falls, high-energy impacts, crushing or piercing injuries, etc.) but have been caused by hazardous substance or other exposures. The evidence revealed through epidemiological studies, sometimes years after exposure first commenced, has confirmed the need for those widespread controls demanded by regulation. Consider the evidence provided by the following examples which indicate the scope for delayed work-related ill health and death from chemical or radiation exposure:

World's worst single-event industrial disaster (with the probable exception of Chernobyl)

- Bhopal in 1984, involving the inadvertent release of methyl isocyanate (a component in pesticide manufacturing) and resulting in the deaths of 2000–2500 persons and injuries caused subsequently to some 17 000 more who lived in the environs of the factory. Though the cause from chemical exposure was soon evident, the scale was not so immediately obvious.

America's worst individual industrial accident

- Hawk's Nest Tunnel, built for water diversion in the early 1930s, in which more than 600 men died within a period of 2 to 5 years from silicosis. In this case, neither the cause nor the scale was obvious at the time of the work.

Australia's worst industrial accident

- Wittenoom blue asbestos mining (which commenced in the 1940s), Western Australia, from which a probable 2000 persons will die from asbestos-related diseases, including mesothelioma. The cause and scale of the disaster were totally underestimated.

The world's incidence of mesothelioma and lung cancer associated with asbestos exposure, unfolding through the latter part of the 20th and the start of the 21st centuries, will probably reach several hundreds of thousands.

All of these 'accidents' were related to exposures arising from a workplace. They all demonstrate that exposure to hazardous substances can cause severe ill health or death. In the asbestos-related cases, the exposures were not treated as being dangerous at the time.

In the 1980s, the United States National Institute for Occupational Safety and Health (NIOSH) identified the 'top ten' workplace injuries and illnesses (US DHHS 1985). The list included occupational cancers, dust diseases, musculoskeletal injuries and hearing loss, and a number of other causes still with us today. NIOSH reviewed the situation in 1996 and estimated that 137 persons died each day in the United States from work-related illness and 16 died from traumatic injury. This review led to a change in emphasis and the emergence of its National Occupational Research Agenda (NORA), in which 'leading causes' have been replaced by the research topics shown in Table 1.1, which emphasise those areas most important to occupational health and safety (NIOSH 1996). It should be noted that research interest is no longer restricted to injury and illness, but now includes the scientific and medical tools and social factors surrounding the workplace and its organisation. This research trend is being observed in many countries.

Table 1.1 NORA's research topics important to occupational health and safety

Topic	Typical interests
Disease and injury	
Allergic and irritant dermatitis	Solvents, cutting fluids, latex, engineering controls, pathology, colorimetric indicators
Asthma and chronic obstructive pulmonary disease (COPD)	Respiratory sensitisers, isocyanates, food flavourings, machine aerosols, schools and offices, textile workers, burden of COPD
Fertility and pregnancy abnormalities	Solvents, pesticides, sterilants, antineoplastic drugs; male health and reproduction; birth defects; semiconductors, endocrine disrupters
Hearing loss	Solvents and ototoxic effects, heat, engineering control strategies, protector effectiveness, carpenters, miners
Infectious diseases	Healthcare workers: HIV, hepatitis B & C, tuberculosis, prevention of transmission; special interest in SARS and bioterrorism
Low back disorders	Intervention through engineering and task redesign; hospitals, construction, neuro-fuzzy prediction, mobile equipment, vineyards
Musculoskeletal disorders of upper extremities	Repetitive work and fatigue, mechanisms and controls, vibration, garment, automobile and nursery workers
Traumatic injuries	Mobile equipment, vehicles, machines, falls and being struck etc., surveillance and data collection, dissemination, analysis, public health model use, passive controls including engineering pursued
Work environment and workforce	
Emerging technologies	Nanotechnology, biotechnology, gene technology, telecommunications, recycling, prediction, smart fire sensors
Indoor environment	Building-influenced communicable disease, asthma, allergic disease, non-specific respiratory disease, controls, floor supply ventilation, aircraft cabins

Mixed exposures	Surveillance for mixed exposure workers, understanding toxicology from molecular to whole organism; develop biosensors, characterise response
Organisation of work	Effect of downsizing, outsourcing, contracting and temporary work on quality of life, cardiovascular disease, depression, violence, management
Special populations at risk	Older and younger workers, minorities, immigrant workers, literacy
Research tools and approaches	
Cancer research methods	Occupational carcinogens, epidemiological study design, risk assessment and primary prevention
Control technology and personal protective equipment	Ensuring better acceptance and knowledge of engineering controls; cost minimisation strategies, robotics, personal protection improvement and uptake
Exposure assessment methods	Study design, monitoring methods, applied toxicology, education and communication
Health services research	Healthcare delivery to workers, social and economic factors
Intervention effectiveness research	Reduced injury and illness, employee satisfaction, reduced compensation, increased productivity
Risk assessment methods	Epidemiological, statistical, toxicological methods; dose models, biological models and response
Social and economic consequences of workplace illness and injury	Family impacts, return to work, insurance, career opportunities, cost outcome analysis
Surveillance research methods	Tracking of workplace injury, illness, exposures and hazards

Source: Compiled from NIOSH National Occupational Research Agenda, and <www.cdc.gov/niosh/nora> (January 2005)

Research conducted in Australia for the National Occupational Health and Safety Commission (NOHSC) on the contribution of the workplace to the incidence of injury and disease, provided an enlightening comparison of the relative importance of death from traumatic injury and death from work-related disease (Kerr et al. 1996). Although its method of using attributable disease has been criticised (Christophers & Zammit 1997), the NOHSC report indicated that around 600 persons die each year in Australia from traumatic events in the workplace, and 2200 die annually as the result of work-related ill health.

Health issues are now recognised to be of great significance to the wellbeing of the worker. The H&S practitioner's task is to put hygiene processes in place so that health issues do not go unrecognised nor unattended.

1.5 OCCUPATIONAL HYGIENE

To control both acute and chronic health risks from hazardous materials, physical agents and microbiological hazards, the discipline of **occupational hygiene** has been developed.

How did occupational hygiene arise and why should it be so important? Nearly all the H&S practitioner's tasks in dealing with workplace health hazards involve some aspect of hygiene practice. The word 'hygiene' itself is derived from *Hygiea*, the Greek goddess of health. The major activity of occupational health occurs through the preventive activities of occupational hygiene. Apart from inoculations and prophylaxis which can be provided against diseases such as Q-fever, hepatitis A and B, malaria, etcetera, nearly all occupational health interventions are made to the workplace, not to the worker, or at least through isolating the worker from the hazards arising from the workplace. It is difficult in the ordinary sense to make workers invulnerable to exposure to heavy metals, quartz, asbestos or many organic chemical substances. Particular genetic dispositions may make some individuals more susceptible to hazardous substance exposures than others. On the other hand, because of the human body's capacity to metabolise or excrete hazardous substances, or deal with some amount of noise, heat or radiation, it becomes possible to control exposures to prevent both acute (short-term) and chronic (long-term) adverse health outcomes in workers. However, this requires a very extensive understanding of the nature of hazards in the workplace, how these hazards arise (for example, as dusts, vapours, microbiological or physical agent exposures) and the extent of workers' exposure. It requires a sound knowledge of the risks to health which arise from exposure to each hazard and the level of control which needs to be put into place to control those risks.

Several medical writers across the last 500 years, including Agricola, Ramazzini and Thackrah, made astute observations about how important it was to understand the vocation of a worker to assess the influence of work on working men and to evaluate what might be done to help alleviate their conditions. However, occupational hygiene gained no real impetus during the industrial revolution and had to await the First World War years for advancement, when it was observed that many munitions workers were being made seriously ill from their work. Workplace controls were implemented to control exposure to the propellant charges and some of their poisonous payloads.

From these tentative beginnings where hazards were becoming better recognised, their risks better understood, and controls were being explored, the modern discipline of occupational hygiene grew.

1.5.1 DEFINITION

Occupational hygiene is defined as the science of **anticipation**, **recognition**, **evaluation** and **control** of hazards in the workplace. The H&S practitioner can be involved in all these tasks. The reader should note that the term 'assessment' is often used in place of evaluation, and is the term favoured also in much of the prevailing occupational health and safety legislation throughout Australian states.

Why go to all the trouble of anticipating, recognising, evaluating and controlling, and instead simply ban all hazardous substances or substitute them with non-hazardous ones? Or why not introduce controls which permit no exposure at all?

Firstly, many industries and other workplaces are entirely geared to using a particular substance. Natural products such as coal, stone, iron ore, precious and industrial metal ores still have to be mined. In many chemical processes there are no safer substitutes available, although progress is constantly being sought in this area. Secondly, total exposure control in all hazardous industries is ruled out by economic considerations. Only in exceedingly dangerous industries is this attempted (e.g. industries involving severe biohazards, nerve gases, radioactive hazards). Lastly, imposing total bans or complete control ignores the important fact that some levels of exposure often can be tolerated. Sometimes the exposure produces no adverse biological effect, or the effects are totally reversible, or there is complete recovery after short exposure, or some exposure can be tolerated with minimal effects.

There are thousands of potentially hazardous situations in our workplaces arising from the use of hazardous substances or regular exposure to noise, vibration, radiation, heat or cold. Consequently, no single solution will work for all of them. Nor could any attempt be made to legislate separately for health and safety in each case. Recognising the hazards, assessing the risks, and controlling those risks to an acceptable level will provide the best economic solution to achieving a healthy workplace. Occupational hygiene is really a system of workplace management which finds out just what the hazards are, evaluates the risks and subsequently controls them to a level which is considered acceptable.

There is no set formula to follow in an occupational hygiene investigation. All workplaces are different. But four basic principles apply:

- **Anticipation** of problems is considered a vital skill, but while this usually requires considerable experience, assistance is now provided by material safety data sheets (MSDSs) and abundant advice available in the literature, various databases and electronic sites.
- **Recognition**—knowing the hazards, the processes or identifying them through adverse health effects.
- **Evaluation**—measuring exposures, comparing against standards, evaluating risk.
- **Control**—providing contaminant or hazard control; the level of protection is based on knowledge of the toxicology or adverse effects produced by known quantitative exposures to the hazard.

To carry out occupational hygiene some special skills and knowledge are needed; these can be developed in the workplace with appropriate guidance from this book. Some of the knowledge of health effects which underpin the need for control is provided in the book. For example, where the book examines dusts in the workplace, the discussion covers why those dusts are hazardous to health and those common workplace situations where such hazards arise. However, all H&S practitioners will need to pursue additional sources of information to keep up with the expanding OH&S field. Secondly, assessment skills will be developed through the use of basic measuring skills, understanding of monitoring programs and correctly using exposure standards to gauge risk. Lastly, skills needed for proper control of the risks are gained from the combination of recognition, assessment and understanding correctly how controls are intended to work.

Specific training courses in occupational hygiene are also available in Australia. The Australian Institute of Occupational Hygienists (AIOH) provides details of occupational hygiene training courses on their website and accredits some courses.

The H&S practitioner should become familiar with the processes of anticipation, recognition, assessment and control from examining their own workplace. An employer may also use a specialist consultant hygienist who should be able to assist in workplace evaluation and control of workplace hazards. The AIOH has a list of consultants and their areas of expertise.

1.6 RECOGNITION OF HEALTH HAZARDS IN THE WORKPLACE

Recognition of health hazards in the workplace is fundamental to their proper control. Occupational disease still occurs because employers and their workers are often ignorant about the hazardous nature of materials or processes in their particular workplace. Health hazards often arise from unexpected sources as well as from those which today are well documented. If no attempt is made to establish the nature of hazards, control may be haphazard or even nonexistent. Despite recent development and learning in workplace health, some employers still do not appreciate the potential risks to health from such well-documented hazards as asbestos, lead or pesticides.

How does the H&S practitioner recognise an occupational hygiene hazard? There are a number of ways:

1.6.1 DIRECT HEALTH INDICATORS

- A worker is killed in an acute poisoning incident.
- Workers are becoming ill on the job.
- There are biological or radiological (e.g. X-ray) signs of work-related ill health before any symptoms occur.
- There is increased incidence of a particular symptom occurring among certain workers.
- Death certificates show an increased incidence of death due to a particular cause.

All these indicators might seem drastic, and appear too late to avert adverse health problems. However, most occupational health hazards have been identified by this very process of observing the health effects in workers exposed to them. But recognition of a disease is only one part of the process. Understanding the nature of the contaminant and how the worker can be exposed are the others.

Some classic cases of correctly recognising exposure are:

- Identifying silica exposure in needle grinders in the 19th century. It was believed that inhaled iron particles caused the respiratory disease, but even with the iron removed by magnetic masks, disease continued until silica was identified as the causative agent.
- Recognising that luminous dial painters, prior to the 1930s, who pointed the tip of their brush with their lips and teeth and so were ingesting significant amounts of radioactive radium, were subject to radiation illness, including cancers of the mouth and jaw.

Understanding an industrial process is very important to providing a healthy workplace. The H&S practitioner who is intimately involved in a workplace is often better placed than any consultant or inspector to advise on the work practices and materials used in that workplace. But because the long latency period of many diseases diminishes the utility of using direct health indicators, it is obviously not a good strategy to wait until workers become ill.

1.6.2 USING PREVIOUS EXPERIENCE AND INFORMATION ALREADY AVAILABLE

There is now a very large body of information available on health hazards in the workplace and their effects on workers. For example, if a workplace uses solvents and metal dusts, is noisy and hot, there is sufficient information available to already assist in recognising the potential hazards. To determine the level of potential for harm to health will require a risk assessment.

The most immediate source of information is the material safety data sheet (MSDS) (see Chapter 14, Sources of Information). Throughout all jurisdictions in Australia since the mid-1990s, all hazardous substance manufacturers and importers have been obliged to produce an MSDS for each substance in a standardised format, based on NOHSC guidelines. The MSDS will identify the major health concerns of the hazardous substance and the basic requirements for control. Supplementary information sometimes must be sought. By law, all MSDSs must be available in English.

However, in many instances, a hazardous substance exposure can occur in a workplace without the benefit of an accompanying MSDS. Consider the following well-established hazards to health in these workplaces:

- methylmethacrylate exposure in synthetic nail boutiques
- formaldehyde exposure arising from particle board manufacture and use
- cristobalite exposure in beer production
- isocyanate exposure in polyurethane foam manufacture
- MOCA (a chemical catalyst) exposure in polyurethane rubber manufacture
- acid vapour or cyanide exposure in electroplating
- metal fume and oxidant gas (e.g. ozone) exposure during welding
- asbestos exposure in building maintenance involving sawing asbestos cement sheet

- asbestos exposure from asbestos stripping operations
- oxides of nitrogen and aldehyde exposure from diesel exhaust fumes
- carbon monoxide exposure from vehicle exhausts in underground car parks
- psychogenic drug exposure in (legitimate) plant harvesting and processing.

In each of these work situations the hazards are well known, but in only the first six or seven will an MSDS be available for a hazardous substance to alert employers and workers to risks and to advise on control methods. For example, there won't be an MSDS on asbestos stripping because the asbestos was almost certainly in place before MSDSs were created. Similarly, no MSDSs will be available to review vehicle exhaust emissions. Other regularly-arising risks to health such as those from radiation, noise and heat come with no means of advice such as an MSDS. In these latter cases, the H&S practitioner will need to refer to other information sources. About half the usual work of the H&S practitioner will require obtaining information not readily accessible at the workplace on an MSDS.

Sources of information vary in quality, accessibility and usefulness; some of the most valuable are mentioned in Chapter 14, Sources of Information.

1.6.3 OBSERVATION OR USE OF SPECIALIST EXPERTISE

1.6.3.1 The material inputs

When a hazard is not immediately identifiable by referring to an MSDS, the H&S practitioner must check all process materials for potential health hazards—for example, solids may give off dusts, liquids may produce aerosols or vapours, and gases may escape to contaminate workplace air. Noise or radiation may be emitted. Expert opinion and guidance may be necessary once fumes, gases, dusts and vapours are identified.

1.6.3.2 The process

The work process itself may generate the hazard from apparently innocuous precursor materials. The hazard may not be recognised until detailed tests of the environment have been conducted.

In these cases, understanding the nature of the process and the materials is extremely important. Consider the following real-life examples:

- acid and cyanide solutions both present in electroplating workshops, which if accidentally mixed in a distant drain may create an extremely high risk from exposure to hydrogen cyanide vapour
- use of ultraviolet lamps for setting of UV-curable resins generates ozone
- pyrolysis (burning) of materials may produce breakdown products from materials normally biologically inert (e.g. fluorine compounds from combusted Teflon®)
- production of hydrogen chloride from some decomposing chlorofluorocarbons or burning of PVC plastic
- generation of phosgene by a high-energy input (e.g. a welding flame) creating breakdown products of chlorinated hydrocarbons
- generation of asthma-producing agents from colophony rosin in solder.

Each of these examples involves hazardous substances, but physical agents associated with a process are just as important to identify. Equally important are biological hazards, where the agent may be difficult to recognise, as are the processes which transmit them (e.g. droplet transmission, body fluid exchange).

The most practical method of implementing a **recognition** step in a workplace is by the 'walkthrough survey'. Exposure assessment, health surveillance and perhaps even epidemiological surveys may need to follow.

1.7 USE OF THE PRELIMINARY OR WALKTHROUGH SURVEY

The ability to conduct an effective walkthrough survey is an important skill for an H&S practitioner. It should be routinely used to look at processes and materials. Many hazards can be identified and problems revealed by this simple approach. Use of checklists is highly advisable.

The basic observations of a **walkthrough survey** include:

- the process
- the materials used or handled
- the number of workers involved
- evidence of reactions, any material transformations (generated substances) including wastes
- engineering controls in place
- housekeeping at the process site
- visible conditions at the site (any dusts, mists)
- possible routes of entry (inhalation, skin, ingestion)
- personal protective equipment available and in use.

Associated information for hazard control includes:

- records of material flows or changes in process inputs
- records of process control (temperatures, pressures, data records)
- any records of machine or equipment maintenance or failures
- reports of any incidents or accidents.

Experienced workers on the shop floor will know most about an operation, the idiosyncrasies of machinery (and operators), processes, and so on. Actual practice may be quite different from what the plant engineer or owner thinks is happening. Workers adapt procedures, and sometimes equipment, to suit their own work patterns or physical build. A worker's opinion should be sought on problems with machinery, controls and problem materials. Questions should be asked about exposure to hazardous substances, or hazardous processes, and details recorded. It is also very important to ascertain if the worker has had appropriate training to deal with hazards with which he or she is working. The three illustrations comprising Figure 1.1 show auditors carrying out a walkthrough survey in part of a drum manufacturing plant. Observations are made of the details of paint mixing and pouring, noting the substance

Figure 1.1a
Conducting a walkthrough survey in a drum plant; observing the mixing process

Figure 1.1b
Conducting a walkthrough survey in a drum plant; observing the process of preparing automatic spray-painting machines

Figure 1.1c
Conducting a walkthrough survey in a drum plant; identifying handling processes creating noise

details, recording how the operator executes each task, and observing potential for exposures and any personal protection worn. In the lid-stamping process, the potential for excessive noise exposure and existing hearing protection, together with additional repetitive ergonomic stressors, are all noted.

1.7.1 SOME TYPICAL PROCESSES TARGETED FOR HEALTH HAZARDS IN WALKTHROUGH INSPECTIONS

The following list gives an idea of the types of processes which typically give rise to occupational health and hygiene hazards in workplaces. It is just a start. The H&S practitioner's workplace will provide other examples.

Abrasive blasting typically uses steel shot, copper slag and heavy metal sands (ilmenite), and produces much fine dust requiring operator protection. Dangerous quartz-bearing (river and beach) sands require extensive control and are banned in some Australian jurisdictions.

Agriculture and farming There is a wide range of planting, harvesting and crop management practices involving hazardous dusts, pesticides and herbicides, and microbiological hazards associated with moulds and fungi. Dangerous gases may arise in silage pits. Ultraviolet radiation from the sun is a problem, as can be heat stress, tool and vehicle vibration, and noise exposure.

Animal husbandry Parasites, biological hazards, immunological sensitisers.

Bagging and pouring of powders and dry materials Many processes involving powders produce fine dust which can be inhaled. These processes include the manufacture of paints, pigments, resins, pharmaceuticals, animal feed stocks, foodstuffs, cements and fillers.

Buildings and the built environment Enclosed buildings produce a range of occupational health hazards ranging from volatile organic compounds from electronic office equipment, to gases given off by building products, carbon dioxide build-up from exhaled air and microbiological hazards (moulds and fungi).

Chemical reactors are used widely in the production of gases, liquids and solids which may be toxic. These form the basis of most chemical manufacturing, such as oil refineries, plastics manufacturing and cyanide production.

Coating operations involve a wide use of organic and inorganic powders, suspensions and solutions. Materials are usually sprayed or rolled, producing aerosols of organic materials, as well as a range of vapours or dusts.

Crushing and grinding This usually involves size-reduction processes, often done dry, sometimes wet. Many naturally occurring raw materials processed in this manner can produce dusts, often accompanied by severe noise hazards.

Drying ovens are widely used in manufacturing, art and craft, and industrial surface coating. Ovens produce vapours from solvents, lacquers, paints, cleaning agents and plastic resins, as well as combustion gases from fuels.

Electromagnetic operations Industrial processes using radiofrequency induction furnaces, microwave heaters, X-ray equipment and radar signal generators are all able to produce biological effects unless equipment is properly shielded. Some may affect surgically implanted electronic devices such as pacemakers. Magnetic fields in large direct-current metal smelters may do likewise. Electric fields from high-voltage transmission may affect power-line workers. Radio and microwave transmission towers produce significant risks in near-field radiation zones.

Gas reactions and gassing procedures Production of gases for petrochemicals, synthesis of plastics, rubbers, fuels, in catalysis, fumigations and sterilising have the potential to give rise to serious inhalation hazards. Anaesthetic gassing in hospitals may create bystander risk.

Mechanical work such as sawing, drilling, planing, sanding A principal group of industrial operations which may produce a wide range of workplace hazards depending on the nature of the material worked. Hazards to be aware of include noise, toxic dusts from metals, woods, plastics, rocks and asbestos, and vapours and gases from decomposing plastics.

Mining Production of dusts, radioactive gases, vehicle exhausts, noise and vibration hazards. Also chances of asphyxiation, poisoning by various gases and severe explosion hazards.

Painting covers a wide number of processes including spraying, brushing and roller-coating. Nearly always involves solvent vapour exposure; may involve toxic metals, severe irritants and respiratory sensitisers.

Pyrolysis (burning) Deliberate or accidental burning of industrial products, particularly synthetic materials, produces a range of toxic or irritating gases, vapours and smoke.

Plating Industrial processes involve skin risks from acids and alkalis and inhalation risks from corrosive and toxic aerosols and gases.

Smelting and hot metal handling Metal fumes, gases and vapours from decomposition of moulds, heat and radiant energy, noise and light.

Vapour degreasing Widely used industrial process, with hazards from vapour inhalation and skin and eye contact.

Washing may involve a wide range of processes and products from water-based materials, to acids, alkalis and organic solvents. Gives rise to a range of skin contact problems, inhalable aerosols and vapours.

Welding, soldering and thermal metal cutting Essential industrial processes producing a range of potentially toxic metal fumes from welded material, welding rods or fluxes. Irritant and oxidising gases can also be produced, together with inert, asphyxiating gases from certain welding technologies.

Later chapters look at specific health hazards in workplaces in much greater detail. The short list above should give some idea of the dimension of the **recognition** problem. Recognition may be complicated in the following ways:

- many health hazards cannot be seen
- many substances have no adequate warning smell
- harm which can be induced by many physical agent exposures is not understood by workers and employers
- workers do not know what their exposure is
- many employers and workers still have inadequate information on potential health effects through lack of risk assessments

- employers and workers may fail to recognise chronic risks from chemical exposure if acute harm is not experienced.

The H&S practitioner should now understand better why workplace health problems tend to have been overlooked. Safety problems are generally much easier to recognise.

1.8 EVALUATION

Once a walkthrough inspection of a workplace has been done, most potential hazards should have been identified. Let us take a machine shop as an example. Table 1.2 identifies various hazards which are typically found to be associated with a number of processes in a machine shop.

Table 1.2 Hazards to be identified in a walkthrough survey of a machine shop

Process	Hazard identified
Welding	Respiratory—metal fumes and oxidant gases Skin and eye—ultraviolet radiation
Solvent degreasing	Respiratory—chlorinated hydrocarbon vapours Skin—worker's hands directly exposed to solvents
Spray painting	Respiratory—organic solvent vapours, aerosols from isocyanate two-pack paint system Skin and eye—from paint mixing and paint aerosol
Lathe milling	Respiratory—mists containing organic microbiological growth inhibitors and biohazards from aerosols of cutting oils
Drill press	Respiratory—fibrous dusts from drilling friction materials
Metal polishing	Respiratory—polishing compounds (e.g. tripoli) containing crystalline silica Noise

Some hazards can be seen, most cannot, but all need evaluating. It may be difficult to reconcile that all or any of these operations could be dangerous to health, since workers in such places seldom complain of ill health and often seem prepared to tolerate the dust, fumes and noise. Simply identifying the risks does not determine their significance, however.

The next task is to **evaluate** the risks associated with the hazards. But why evaluate? There are several good reasons. Evaluating the risk allows the H&S practitioner to determine the answers to these questions:

- Is the particular risk from exposure acceptable?
- Does it meet regulatory requirements?
- Will it need controlling to make it healthy and safe?

- Are there special controls for this hazard?
- How much control is needed?
- What is the most effective control mechanism for this process?

There are, of course, many situations where evaluation of the risks will show that no action is needed. Experience may provide a guide to assessing risk without measurement, provided there are adequate indicators such as odour or visual cues, and production parameters and so on are known. However, it usually takes an occupational hygienist a decade or so of experience to be able to make such judgments, all with instrumental verification as back-up. The eye cannot judge a concentration of 0.1 mg/m^3 of quartz dust particles it cannot see; the nose cannot judge 0.02 mg/m^3 of isocyanates vapour it cannot smell, nor can the nose judge the concentrations of various organic vapours in a mixture; the ear cannot judge the integrated noise dose of intermittent or impulse sounds. There is often no substitute for proper instrumental evaluation.

1.8.1 EVALUATING THE RISKS FROM A HAZARD

Evaluation of a risk is now most often referred to as the process of **risk assessment**.

All state and territory occupational health and safety (OH&S) jurisdictions require a risk assessment for work with hazardous substances, and they often provide a range of protocols to assist. Other hazards, such as noise, heat, radiation and biological hazards, are likely to require similar risk assessment processes. Evaluating the risk allows the most economic decision to be made regarding controls. It also allows a solution to be tailored to suit the workers and the work operation. It is worth remembering that workers may be exposed to more than one hazard at a time. Evaluations need to consider all possible hazards and the ways they may affect workers.

A typical regulatory risk assessment can be pared down to the following essentials:

- examine the process in which the hazard is generated
- determine the means by which the hazard is dispersed into the workplace
- identify the health effects caused by the hazard and the likely routes of entry
- estimate likelihood of health effects resulting from exposure by:
  - monitoring the exposure of the worker to the hazard (e.g. a substance, noise, lighting)
  - comparing this exposure with recommended exposure standards or limits
  - deciding whether there is a risk to health or safety
- determine the extent of controls needed
- decide whether there is a need for ongoing workplace monitoring/measurement and health surveillance.

1.8.2 SOME TYPICAL EVALUATIONS

The H&S practitioner would be expected to be able to conduct most risk assessments for which instrument measurement is not needed and should also be able to carry out some simple measurement evaluation tasks. Examples of both are described below. Complex evaluations require resources which average workplaces cannot economically justify; frequently they also require technical expertise and experience which the H&S practitioner will not normally have. Nonetheless, the following chapters discuss most of the important details about more complex evaluations. For example, if a workplace has workers exposed to respirable quartz, the practitioner will need to be able to identify the correct sampling equipment, the methods of sampling, how the respirable quartz is measured, what its exposure standard is, and the important features of conducting a monitoring strategy. This detail is provided to assist the H&S practitioner to know how to select a competent consultant to provide the more advanced services and how to assess the quality of the consultant's work and reports.

1.8.2.1 Example of a simple evaluation

Figure 1.2 shows the use of an adhesive containing solvent in a workshop.

Figure 1.2
Evaluation of a simple workshop operation

Here the situation is characterised by occasional and limited (10-minute) use of an adhesive which has a moderately volatile vapour with a strong aromatic odour. The MSDS and label have identified the solvent as xylene and health information and advice on precautions for safe use are provided. Xylene is a flammable liquid (consisting of three isomers) and is commonly used in adhesives, solvents, paint vehicles, etc. The boiling point of the mixture of isomers lies between 138°C and 144°C and vapour pressure between 7 mm and 9 mm mercury at room temperature. Overexposure to xylene can cause headache, lassitude and irritability. It can irritate the eyes and nose, and in high concentrations may cause narcosis, blood disease and amnesia. But because of its relatively elevated boiling point (range), and an exposure standard of 80 ppm (parts per million), air monitoring is considered unnecessary as the exposure time is very short and only a small amount of material is used. Low risk is determined. If the procedure was conducted on a more extensive or continuous basis, the risk would need to be re-evaluated with exposure monitoring. This type of evaluation is within the capability of H&S practitioners who have the relevant experience and knowledge.

1.8.2.2 Examples of an evaluation requiring some basic workplace monitoring

The next two examples, both again within the capability of the experienced H&S practitioner, illustrate situations where basic workplace measuring skills are needed. Both are typical of those workplaces where the risk cannot be properly evaluated without resort to a basic measurement.

Basic noise monitoring using a sound-level meter is shown in Figure 1.3. The H&S practitioner is required to assess the worker's workstation for the noise levels which arise from constant use of the pneumatic chisel. A sound-level meter is used to measure the noise level impinging on the worker's ear and then dose $L_{A,Eq,8h}$ can be approximated. Details on methodology and interpretation are found in Chapter 10, Noise and Vibration.

Figure 1.3
A pneumatic chiselling task with basic noise monitoring (*Source: EDI Rail*)

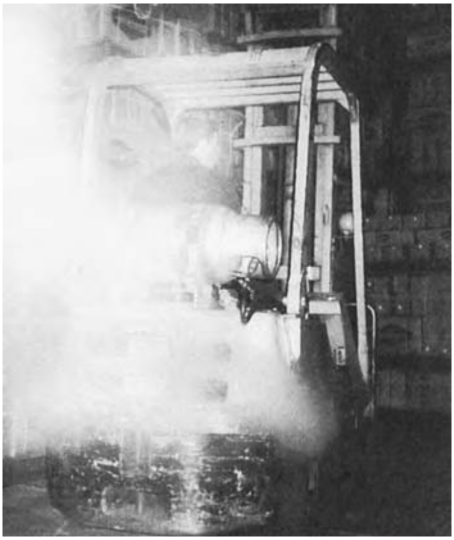


Figure 1.4
Exhaust gases from a forklift in a cold room

Operation of an LPG forklift in a coldroom is shown in Figure 1.4. In this example, the H&S practitioner is expected to be able to use a simple passive diffusion monitor to evaluate the operator's exposure to the carbon monoxide produced by the forklift exhaust. Details for this type of work are found in Chapter 7, Gases and Vapours.

In both these examples, exposure to the hazard increases risks to health. In the case of the pneumatic chisel it is the risk of developing noise-induced hearing loss, and in the case of the forklift it is the risk of chemical asphyxiation due to exposure to carbon monoxide in an enclosed space. Additional information to help the H&S practitioner in the evaluation, such as interpreting the monitoring results, will be obtainable from codes of practice, standards or other advisory documents.

1.8.2.3 Example of a complex evaluation requiring outside assistance

The ferrous and non-ferrous foundry (Figure 1.5) is a typical situation in which the H&S practitioner will require outside expertise. In foundries there is a range of hazards present, some well documented, others with scarce data. They arise from a variety of different processes as well as the raw materials involved—for example, silica sand, coal dust, chemical binders, vapours such as toluene, isocyanates, furfuryl alcohol, formaldehyde and amine curing agents. In addition, decomposition products such as sulphur dioxide, carbon monoxide, cyanide, formates and ammonia may be present. Noise, heat, vibration, radiant energy and electromagnetic fields can also occur in these workplaces.

Figure 1.5
A foundry workplace requiring a complex evaluation (*Source: EDI Rail*)

In foundries, extensive monitoring is required to evaluate the risks from all these hazards and extensive hygiene resources will be needed. In addition, medical expertise may be necessary for respiratory-function testing of those exposed over a long period of time to dust and the many other respiratory hazards. Such complex tasks are presently considered outside the range of the H&S practitioner.

1.9 CONTROL

Control is central to working safely with processes and substances hazardous to a worker's health, but remains the area least understood and most poorly implemented in many workplaces. Indeed, if control were adequate, occupational ill health would be nonexistent. While much of the failure to implement correct controls arises from ignorance of the risks, some of it results from a cavalier attitude of accepting unnecessary risk to workers' health held by management and even workers themselves. Quite often the hazards are recognised and the risk has been established, but the option of controlling the exposure has been judged as being 'too hard', 'too much trouble' or too costly. Ineffective and half-hearted control procedures are relatively common. Some may lead the operator into greater risk than would otherwise occur because of the mistaken belief that protection has been assured. Extraction systems are often poorly conceived and under-designed. Extractors are supposed to defy the laws of physics and collect vapours magically from points distant from the normal direction of airflow. Buildings fitted out with materials off-gassing volatile components may be sealed with little provision for fresh air exchange. Respiratory protection is often implemented without proper selection, without fit-testing programs and without any planned maintenance, thus rendering it ineffective.

Control of risk is the central requirement of all OH&S health-based regulation, either by eliminating the hazard or minimising the exposure. Control methods that eliminate risks are preferred over those that reduce risks. Similarly, different approaches to control risks may be preferred over others. A framework known as the Hierarchy of Controls, prioritising the preferred approaches to control, is widely accepted and in some jurisdictions is mandated by legislation. Similar strategies apply to many other health hazards in the workplace. In all situations, recognition and evaluation should lead to control.

However, for the H&S practitioner, implementing the correct quality of control requires adequate knowledge of a number of factors which involve both recognition and evaluation. Introducing controls requires knowledge of:

- the hazard
- the degree of risk from the exposure
- routes of entry
- various practicable control strategies—that is, the Hierarchy of Controls: elimination, substitution, isolation, ventilation, administrative controls, personal protection
- how much control is required
- comparative effectiveness of different control procedures
- the relative costs of implementation

- maintenance and testing procedures for control procedures
- user acceptability over long periods
- any social impacts of implementing controls (e.g. workforce-orientated control).

Control is the action end of the work of the H&S practitioner. While H&S practitioners will not be required to design complex controls such as ventilation extraction, they will be required to implement most other control procedures, particularly those involving personal protective equipment. Though a useful skill for the H&S practitioner, ventilation measurements are best left to competent persons with the necessary measuring equipment and skills. However, a broad understanding of different types of workplace ventilation and typical applications is essential, particularly for industrial process. But above all, a thorough knowledge of the various control options and their effectiveness will serve the H&S practitioner well.

Chapter 4, Control of Workplace Health Hazards, addresses in some detail the general principles of the different methods of control for hazardous substances in the workplace. Various requirements for dealing with specific hazards are to be found in the chapters dealing with dusts, metals, gases and vapours, microbiological hazards and so on.

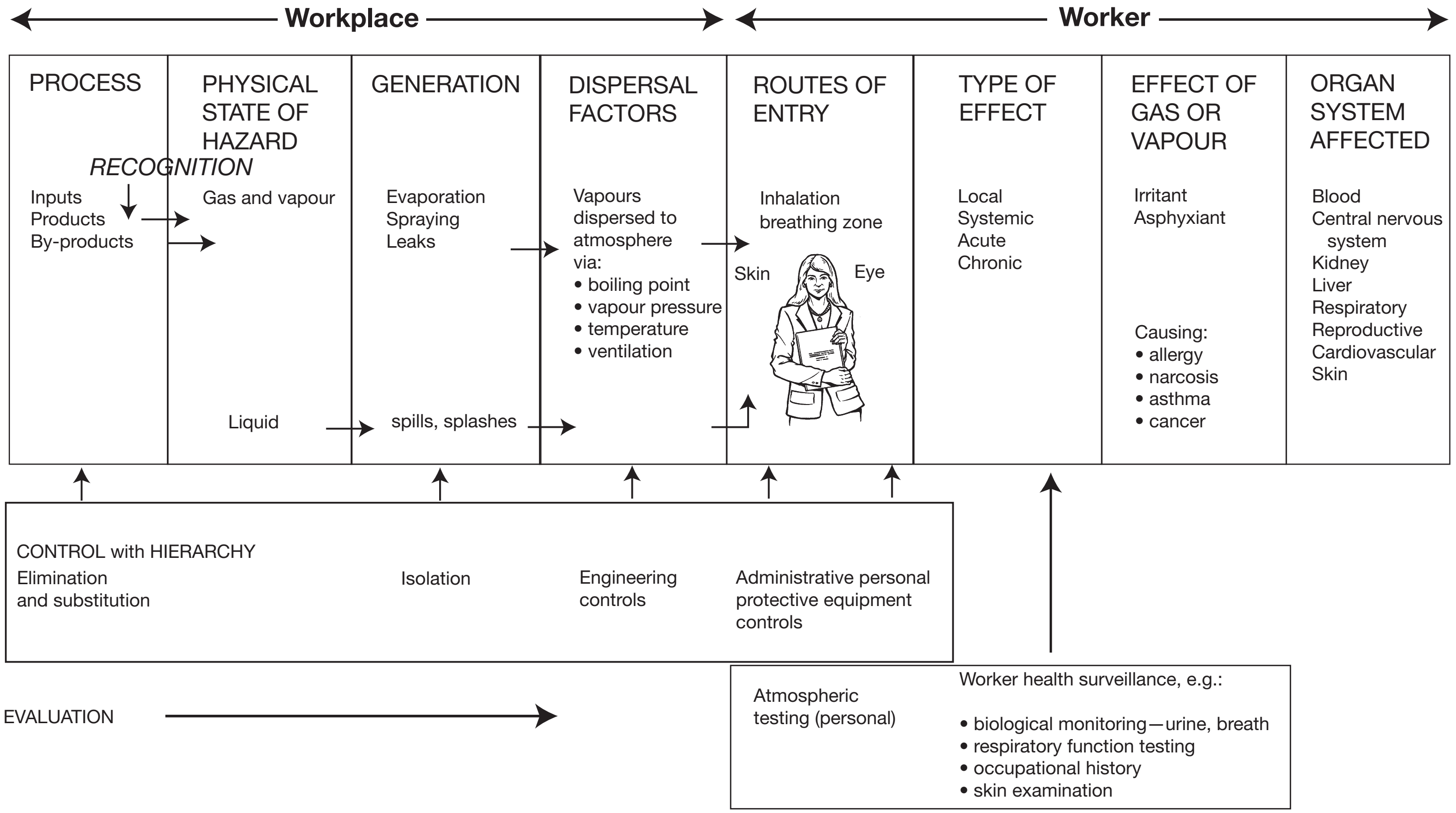
1.10 THE OCCUPATIONAL HYGIENE FLOWCHART

The H&S practitioner needs a practical method of considering the relationships between recognition, evaluation and control. The **occupational hygiene flowchart** shown here gives a visual indication of how all these factors interrelate and has the principal advantage of being able to introduce a most important concept—the **worker**. All hygiene problems must now be considered in terms of both the **workplace** and the **worker**.

A hygiene flowchart can be constructed for nearly all hygiene hazards. The flowchart in Figure 1.6 is a generic one which could be applied to gases and vapours. It has five basic elements:

1. A process of some kind exists which generates a hazard.
2. There is potential for the hazard to propagate throughout the workplace.
3. Workers are exposed via various routes of entry.
4. There is potential for development of disease in the workers.
5. There is potential for different interventions to control exposure and minimise adverse health outcomes.

This flow chart shows that an industrial process generates a hazard and that there are factors which govern how it might escape into the workplace and how it is dispersed. When it reaches the worker, the potential routes of entry take on significance, as do the type of effect and the particular diseases it might cause. For example, some health effects may occur immediately (acute) but other effects won't manifest unless there is a long-term (chronic) exposure. These are all part of the **recognition** phase. Along the centre of the flow chart sits the **control** hierarchy, showing approximately where each control is administered. Note there will be just a few examples



In the occupational flow chart for gases and vapours (which may also derive from liquids), the three hygiene steps are separately identified. Most arrows eventually point to the worker. Other than personal protective equipment, most intervention is in the WORKPLACE, although some administrative controls operate by varying worker involvement. Health surveillance and monitoring are conducted on or with the WORKER.

Figure 1.6 Occupational hygiene flow chart for gases and vapours where it is possible to use a medical control to intervene at the level of the worker (such as inoculation against disease). The **evaluation** in this example takes into account any air monitoring on the worker, and even an evaluation of the worker's health by looking for evidence of different diseases or effects on organ systems known to be associated with the hazard. Note also that the position of monitoring is clearly located under the worker, stressing the importance of conducting air monitoring as personal air monitoring, not as location monitoring or on a process in the workplace.

Once the hygiene flowchart process is understood, the H&S practitioner should be able to recognise the important elements which need to be addressed in any similar scenario, whether dealing with a chemical, physiological (physical agent) or biological hazard.

1.11 CONTROL BANDING

The major part of this book deals with the conventional occupational hygiene approach of recognising, assessing and controlling risks from hazards in the workplace, and calls upon moderate application of science and measurement technologies to help determine appropriate controls. This approach remains the most reliable whether dealing with chemical (e.g. dusts, vapours), biological (e.g. bacteria, viruses) or physical agents (e.g. noise, radiation). However, the H&S practitioner should also be aware of an alternative method, that of control banding, which can be used when controlling risks arising from hazardous substances.

In the late 1990s it became apparent that few managers in workplaces in the United Kingdom understood occupational exposure standards and how they should be used (Topping et al. 1998). In Australia, a similar situation has been identified, particularly in small and medium-sized workplaces which demonstrate poor knowledge about exposure standards and poor compliance with the risk assessment process (Grantham 2003). An alternative approach for dealing with hazardous substances, avoiding the need to understand occupational exposure standards, has been developed by the UK's Health and Safety Executive (HSE). Control banding is designed specifically to overcome the problems of cost, complexity and high levels of training needed to conduct a full and conventional hygiene assessment. It can also be used when no reliable exposure standard exists. Control banding is the basis of the Health and Safety Executive's COSHH Essentials (*Control of Substances Hazardous to Health—Easy Steps to Control Chemicals*) (HSE 1999). At the time of writing, the control banding approach has not been officially adopted in Australia, but is under investigation by NOHSC (and its successor organisation, the Australian Safety and Compensation Council, ASCC) to assess its suitability as a generic tool for use in Australian workplaces to assist in the control of hazardous substances. Such is the success of the control banding approach, however, that it is reasonable to expect that it, or a variant, will be introduced into Australian workplaces.

Control banding simplifies the decision about choosing adequate controls by removing any complex risk assessment steps. Measuring a worker's exposure and making comparisons with exposure standards is replaced with a simple banding approach in which a hazardous substance is assigned to a hazard band according to risk statements taken from the MSDS. This hazard band is then used in combination with the substance's volatility/dustiness and the amount of the substance in use to determine the control measures required. The control options take the user directly to a set of pre-prepared strategies which have been found by experience to provide adequate control for that level of risk. The range of control options can be very extensive, typically high in the control hierarchy, and progresses systematically from general ventilation, to engineering control, and then to containment as the level of risk rises. Control banding avoids use of personal protective equipment, except under circumstances of dealing with the special hazard group of chemicals causing harm in contact with skin and eyes.

The simplification comes at a cost. Because there is no way of assessing exposure directly, the controls recommended usually produce a very conservative outcome, which may not be the most resource efficient. Further, this approach cannot give a fully accurate picture about compliance with a regulation, and no epidemiologically useful exposure data are generated. Nonetheless, the method has proved to be both popular and useful, and has the added advantage of being available to users directly online from the Health and Safety Executive (COSHH Essentials, www.coshh-essentials.org.uk/).

The UK's control banding approach is available in different forms. In addition to the generic COSHH Essentials referred to above, there are specialised tools for individual industries such as *COSHH Essentials for Printers*, in which the Control Guidance Sheets are tailored for this industry.

How does it operate? The following abbreviated presentation from the generic COSHH Essentials demonstrates the five steps needed to apply the package.

Step 1 This uses Table 1.3. The hazardous substance is allocated to one of 5 hazard groups (A–E) according to the harm it can cause, and this is gauged by the risk phrase (R) in the MSDS, or a special group (S) for those substances demonstrating risk to skin or eyes.

Step 2 An assessment has to be made of the amount being used—small, medium or large. The HSE's COSHH procedure adopts the following guides:

- small—grams or millilitres
- medium—kilograms or litres
- large—tonnes or cubic metres

Step 3 Determine just how dusty or volatile the substance is.

Dustiness
- low—forms like pellets, prills, waxed flakes
- medium—crystalline and granular solids
- high—light powders and materials which come out of a process which is likely to create fine dusts (e.g. grinding, sanding, pouring)

Table 1.3 Determining what the hazard group is from the Material Safety Data Sheet

Hazard groups A–E (chemicals causing harm when breathed in)				
A	B	C	D	E
R36 R36/38 R38 and all substances that don't have R-phrases in groups B–E	R20 R20/21 R20/21/22 R20/22 R21 R21/22 R22	R23 R23/24 R23/24/25 R23/25 R24 R24/25 R25 R34 R35 R36/37 R36/37/38 R37 R37/38 R41 R43 R48/20 R48/20/21 R48/20/21/22 R48/20/22 R48/21 R48/21/22 R48/22	R26 R26/27 R26/27/28 R26/28 R27 R27/28 R28 Carc cat 3 R40 R48/23 R48/23/24 R48/23/24/25 R48/23/25 R48/24 R48/24/25 R48/25 R60 R61 R62 R63	Muta cat 3 R40 R42 R42/43 R45 R46 R49
Hazard group S (chemicals causing harm in contact with skin and eyes)				
R21 R20/21 R20/21/22 R21/22 R24 R23/24 R23/24/25 R24/25	R27 R27/28 R26/27/28 R26/27 R34 R35 R36 R36/37 R36/38 R36/37/38	R38 R37/38 R41 R43 R42/43 R48/21 R48/20/21 R48/20/21/22 R48/21/22	R48/24 R48/23/24 R48/23/24/25 R48/24/25 Sk	

Source: Health and Safety Executive (1999) *Control of Substances Hazardous to Health—Easy Steps to Control Chemicals*, HSE, Sudbury, UK. (HMSO copyright used under licence)

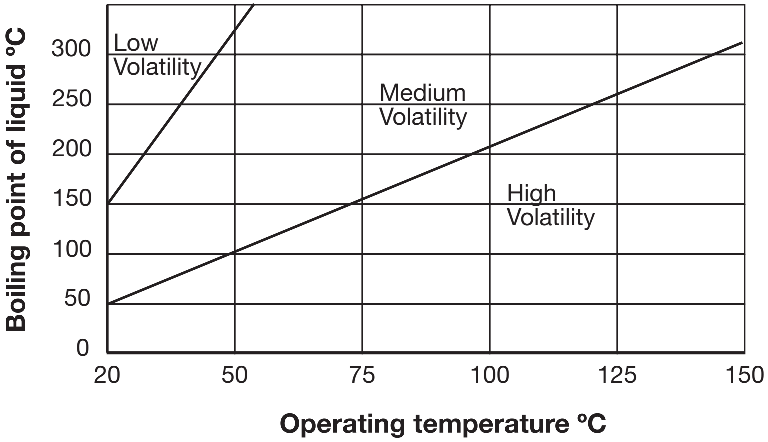


Figure 1.7 Graph to select volatility of a liquid. (HMSO copyright used under licence)

Volatility of liquids
The COSHH Essentials uses boiling point (BP) as a measure of volatility. The boiling point is available from the MSDS.

For processes carried out at room temperature:

- low volatility—those with a BP above 150°C
- medium volatility—those with a BP between 50°C and 150°C
- high volatility—those substances with a BP below 50°C

If the task is carried out above room temperature up to 150°C, then the volatility is amended as determined by Figure 1.7. For example, a solvent with a BP of 150°C is medium volatility if used between 20°C and 65°C, but would have high volatility at 100°C. If it lies near the boundary, choose the higher risk group.

Step 4 Knowing the hazard group, the volatility/dustiness and the scale of use, the task-specific Control Guidance Sheets can be read from Table 1.4. The COSHH Essentials package includes a very large selection of pre-prepared control solutions with drawings and instructions suitable for implementation. There is usually more than one option available.

Note that the COSHH Control Solutions are provided in the following groupings:

- Control Solutions 1 are general ventilation
- Control Solutions 2 are engineering controls
- Control Solutions 3 are containment
- Control Solutions 4 require the user to resort to conventional hygiene practices (or general principles) employing expert advice.

It needs to be noted that this method does not operate for gases, as it is not practical to distinguish between small, medium or large amounts of gas used in a process. Determining controls for gases inevitably requires resorting to conventional hygiene processes.

Table 1.4 Finding the right control approach

Amount used	Low dustiness or volatility	Medium volatility	Medium dustiness	High dustiness or volatility
Hazard group A				
Small	1	1	1	1
Medium	1	1	1	2
Large	1	1	2	2
Hazard group B				
Small	1	1	1	1
Medium	1	2	2	2
Large	1	2	3	3
Hazard group C				
Small	1	2	1	2
Medium	2	3	3	3
Large	2	4	4	4
Hazard group D				
Small	2	3	2	3
Medium	3	4	4	4
Large	3	4	4	4
Hazard group E				
For all hazard group E substances, choose control option 4				

Source: Health and Safety Executive (1999) *Control of Substances Hazardous to Health—Easy Steps to Control Chemicals*, HSE, Sudbury, UK. (HMSO copyright used under licence)

Step 5 Control action is implemented and reviewed. The Control Guidance Sheets usually provide a range of options. Compare with existing controls and choose the most appropriate for your situation. There may be other matters to consider, such as the need to conduct health surveillance. After the control is made operational, it must be reviewed regularly to ensure it is functioning properly and when any change is made in the chemical or its pattern of use.

Control banding is now being promoted collaboratively by the Health and Safety Executive, the International Occupational Hygiene Association (IOHA) and the International Labour Office (ILO). It will be known as the Chemical Control Toolkit.

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2. Occupational health, basic toxicology and epidemiology

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2.1 INTRODUCTION

This chapter is a very basic introduction to the subjects of occupational health, toxicology related to the workplace, and occupational epidemiology. Most H&S practitioners will not need significant expertise in any of these fields even though health studies employing toxicology and epidemiology are the basis of many of our preventive actions. Practitioners needing specific toxicological or epidemiological information will need to consult the literature, some of which is identified at the end of this chapter. Chapter 8, which discusses biological monitoring and biological-effect monitoring strategies that may be applied in the workplace, relies significantly on toxicological principles presented in this chapter.

This chapter discusses the reasons why the approach to occupational health differs from the mechanistic outlook which serves well in occupational safety. The health impacts of hazardous materials and hazardous environments on the human body will be considered. The concepts of hazard, dose and risk, how they are interrelated, and their role in workplace risk assessment will be explained. Lastly, the way epidemiology can provide the link between exposure and disease will be explained.

2.2 THE HUMAN BODY IN THE WORKPLACE

To make any sense of occupational health and occupational hygiene, the H&S practitioner needs a basic knowledge of the human worker and how this human machine interacts with the work environment. The body and its reactions are highly complex. The workplace is a variable mix of different factors, often acting in an uncontrolled way, on the human body. Hence worker–workplace interaction can be tremendously complicated.

The worker's body constantly interacts with the workplace environment and does so in a variety of ways. Some reactions may be testing, others accommodating, some may be defence mechanisms, either on a physiological level (e.g. coughing) or microbiological cellular level (e.g. the development of antibodies). The worker interacts through:

- sensory input—sight, sound, smell, feeling
- ergonomic factors—posture, task, energy demand
- chemical contact—via inhaled air, skin contact
- physical contact—pressure, vibrations, noise, heat, radiant energy, ionising radiation.

Even moderately simple workplace tasks require the service of limbs, motor coordination, balance, vision, lungs, circulatory system, sensory inputs, intellectual input of reasoning and judgment, hearing, use of voice, and body heating or cooling mechanisms. Some of the interactions are perfectly normal and easily within the design capacity of the body to withstand and respond. But if we understand neither the factors in the workplace acting on the worker nor the way the body responds to or copes with these stressors, we will not be able to act to control any resulting strain on the body. Damage and/or illness may then occur.

Organ systems that have no direct contact with the workplace may be those ultimately affected. Hazardous substances entering the body through the lung, mouth or skin may affect the brain, the liver, the kidney, bone or reproductive organs, with the effects being observed even in the offspring of exposed workers.

In order to understand damaging effects, two things must be known:

- What is the worker exposed to (i.e. the potential hazards)?
- What is the body's response?

Both of these can be difficult to establish. Sometimes the factors affecting the worker will not be apparent. For example, in the 19th century needle grinders were thought to be made ill by inhalation of metal splinters, but they were actually affected by the silica from their grinding wheels. X-rays and radioactivity were initially seen as curious and sometimes industrially useful phenomena; their cancer-producing effects were realised too late for many.

Inevitably, two more questions arise. Firstly, are the exposure and the response linked? Secondly, what can be done to prevent the damage to health?

2.3 ESTABLISHING CAUSAL RELATIONSHIPS

We cannot always identify hazards or try to measure the stressing agents in isolation. There could well be many hazards acting simultaneously on the worker. Consider the foundry workers in Figure 2.1. Here the workers are loading, slag-skimming and performing other operations on the top of the furnace and might be subjected to heat, noise, carbon monoxide and fume particles. When tapping the furnace into a crucible for pouring metal into sand moulds they may be additionally exposed to amine fumes, gaseous cyanide and/or isocyanates from mould constituents. The intensity and duration of these exposures will differ at various times during a single work shift.

Figure 2.1

Foundry workers may be subjected to several health hazards, including various dusts, gases and heat (image courtesy R. Golec)

We need to know how the body responds to each and every one of these hazards before any risk assessment can be made in this workplace. Failure to realise that carbon monoxide is a chemical asphyxiant or, worse, failure to recognise that it could be present, could make it difficult to understand why workers can develop headaches in this type of workplace.

Greater complexity arises because the amount of exposure varies. The body exhibits different responses depending on the dose and rate of entry into the body. For example, the foundry workers exposed to carbon monoxide may exhibit headache, loss of concentration and lassitude at low exposures. But exposure to high concentrations (such as from petrol engine exhausts) may lead to severe mental confusion, unconsciousness, coma and death. So the relation between the hazards which exist in the workplace, a worker's actual level of exposure, and the way the worker's body responds requires careful consideration in order to control the situation. Interactions between multiple hazards and their harmful effects also need to be considered. This is especially true where interactions are *synergistic*, meaning that the effect resulting from two hazards combined is greater than the added effects of the individual hazards.

Further complexity sometimes arises when the **causal relationship** is not clear or definite. The association between dose and response may be weak, the response may take years to develop, or several exposures may result in the same sort of response. Experimenting on humans is limited by ethical considerations, so medicine has been forced to develop new ways of eliciting the desired information. One development has been the use of experimental animals as test subjects in studies, the other has been the long-term study of working populations. Indeed, the latter have provided much of our knowledge on the toxicology of metals, dusts, organic solvents, pesticides and microbiological agents. More recent developments of *in vitro* systems and methods, using a variety of cultured cell types, have also provided information on the mechanisms by which chemicals exert their toxic effect. Data from these sources may assist in the H&S practitioner's assessment of risks in the workplace.

However, even after all these efforts to study the hazards and the body's response, we still cannot predict which individual workers in a workgroup will develop disease. Consequently, the significance of prevention for all workers becomes apparent.

2.3.1 MULTIPLE CAUSES OF DISEASE

Another problem to surmount in studying workplace illness is that the body may respond in the same way to several different exposures. Foundry workers may develop asthma from exposure to workplace amines or isocyanates, or their asthma may be caused by pollens and other natural materials and not work related at all. A headache may be the result of dehydration, or excessive noise, or carbon monoxide exposure.

2.3.2 LINKING A HEALTH EFFECT TO A PARTICULAR EVENT

Observation of workers exposed to thousands of different hazardous substances such as asbestos or solvents, or processes such as welding, has provided the basis for making workplaces much healthier. For these well-acknowledged problems, the H&S practitioner can quite confidently use the available epidemiological and toxicological information and recommended exposure standards to facilitate control strategies.

On the other hand, many hazardous substance exposures may lead to effects such as mood or adverse personality change, or loss of memory, which are too subtle to be easily recognised. Most H&S practitioners are not trained to observe such phenomena. Further, materials are constantly being investigated for possible effects such as carcinogenicity (the ability to cause cancer), mutagenicity (the ability to induce mutation in cells) or teratogenicity (the ability to cause defects in offspring). However, cancer, cell mutations and birth defects occur in the general population for a variety of reasons. In order to identify occupational causes, one must show an increase in a particular disease rate following occupational exposure. For example, exposure to radon gas, which occurs naturally in underground mines, can cause lung cancer, but so does smoking. To identify any increase in the incidence of lung cancer in a group of miners beyond that experienced in a comparable non-occupationally exposed group requires specific and sensitive epidemiological methods.

The study of the health of workers and the diseases caused by their work is hence very complex. The tools used by the epidemiologist to provide better understanding of the relationship between exposure and health are presented later in this chapter.

2.4 OCCUPATIONAL HEALTH

Occupational health may be defined as the maintenance of the individual worker's state of wellbeing and freedom from occupationally-related disease or injury. Occupational hygiene is the practice whereby this is achieved.

2.4.1 OCCUPATIONAL DISEASE COMPARED WITH OCCUPATIONAL INJURIES

By now, the H&S practitioner will have realised that successful intervention in an occupational health issue requires much more than a simple workplace inspection and the implementation of a few policies or procedures. Indeed, under most legislation, there are few specific regulations that provide prescriptive courses of action. Any successful intervention in this self-regulatory environment, therefore, is going to require knowledge of:

- the workplace process and the hazards it produces
- the toxicology of hazardous materials
- the health effects of physical, chemical and biological hazards in the workplace
- the effectiveness and appropriateness of different control strategies
- the relative costs of implementation, and
- effective risk communication.

Occupational health diverges from the more traditional view of occupational safety in several ways. These include:

- The H&S practitioner has to intervene without the benefit of being physically able to see the hazard. For H&S practitioners entering from a traditional 'safety' background, this will require new insights in identifying problems and in seeking solutions. In safety matters, one can define the hazards quite readily and also identify some of the outcomes without error. For example, unrestrained moving loads might be expected to fall, unguarded machinery can be expected to mangle limbs, or unsupported excavations can be expected to collapse.
- In dealing with hazardous substances, the H&S practitioner has to be able to identify possible outcomes, even where the worker does not show immediate effects. If workers are in the way when loads fall or trenches collapse, there is a high probability of resulting injury or death. In the case of dealing with potentially hazardous materials or environments, the worker may appear not to be immediately affected, but can suffer disease or even death some time in the future, including after retirement.
- In occupational health there exists a clear possibility of intervention to change the course of events. In the case of accidental injury, intervention is aimed at preventing the event from occurring, since once an accident is underway, intervention is rarely possible. The use of personal protective equipment such as steel toe-capped boots does not prevent the incident but reduces the consequent harm.

Occupational health considerations are all based on a risk assessment. That is, we may reduce exposure to the level where there is an acceptably small chance of harm occurring. The human body can tolerate some levels of some exposures without detriment. Hence, in general, occupational safety deals with accidents and their prevention, while occupational health deals with occupational diseases and their prevention.

A sudden injury at work can differ from disease caused by work exposures in three ways. These are the **time factor**, the **damage factor** and the **dose factor**.

2.4.1.1 The time factor

- An accident and the resulting injury occur at virtually the same point in time and from a single incident. This immediacy of injury means that the link between cause and effect is obvious.
- Occupational diseases may occasionally result from single massive exposures but usually result from exposures to the causative agent over a period of time. The disease may take some time to develop, ranging from minutes to years.

Examples include:

- carbon monoxide poisoning—minutes
- solvent intoxication—hours
- metal poisoning—days
- noise-induced hearing loss—years
- asbestos-related diseases—up to 50 years.

Some health effects appear long after exposure has ceased. Consequently it is important to recognise that workplace exposure to hazardous substances can be equated to accidents occurring over a long timespan. The typical timespan for asbestos-related diseases, for example, may be 15 years for asbestosis, 20 years for lung cancer, and 30 years for mesothelioma.

2.4.1.2 The damage factor

- An accident may injure tissues but only where the energy of the accident is applied, for example, a part of the body such as the head or the arm.
- With disease, tissue damage may or may not occur where the causative agent is applied. For example, inhaled quartz dust has a direct effect on the lungs, but inhaled solvent vapours may produce effects on the liver or on the brain such as headache or drowsiness.

In addition, subtle changes which are not obvious to the worker may occur to body functions. For example, small amounts of lead produce changes to blood formation even though the person remains quite well, whereas absorption of larger amounts will cause frank illness.

2.4.1.3 The dose factor

Disease may be caused by a single large exposure or many small exposures to a workplace hazard. The likelihood of disease depends on the dose received. There may be some threshold dose, below which there is no adverse effect, which will vary depending on the hazard. It will be very small for highly hazardous agents, and large for those of lower hazard.

Throughout following chapters the significance of this dose factor will be discussed. Different doses can provoke different responses in the case of exposure to dusts, metals, gases and vapours. The dose to which a worker is exposed affects the interpretation of risk and the kinds of controls we should use.

2.4.2 WHAT THE H&S PRACTITIONER NEEDS TO KNOW

Because of these three factors, **time**, **damage** and **dose**, the link between cause and the resulting occupational disease may not be immediately obvious. Therefore, to prevent disease, or to detect minor change early before the worker becomes ill, it is essential to have a knowledge of the conditions in the workplace which make it a risk to health.

Detection and prevention of disease require an understanding of a wide array of work situations and knowledge of the effects that various hazardous agents can have on workers. Therefore it is necessary for the H&S practitioner to seek good occupational hygiene knowledge of:

- those agents in use at the workplace which are hazardous
- how much exposure poses a risk
- what procedures are necessary to monitor the workplace and worker exposure
- how exposure can be controlled.

Only when armed with this information can the H&S practitioner responsible for occupational health take steps to prevent work-related illness. The succeeding chapters provide details of workplace investigation, toxicological information on some regular workplace hazards, guidelines on how to assess the hazards and, lastly, a wide range of control techniques and methods. This information will not make the H&S practitioner an expert, but should provide a foundation on which to build. Only practical experience will permit mastery over real work situations.

2.5 BASIC TOXICOLOGY

Toxicology may be defined as the description and study of the effects of a substance on living organisms. In terms of the workplace, we are interested only in human toxicology. Few animals, even the canary used historically in mines to warn of poisonous gas exposures, are used nowadays in workplaces. Nonetheless, animal toxicology has provided valuable insight on potential effects of hazards to humans. Experiments on animals of prolonged or high exposure to various hazards, which can be carried through to their death or sacrifice, obviously cannot be conducted on human populations, for ethical reasons.

The H&S practitioner needs to understand basic toxicological concepts in order to:

- understand recommended or regulatory exposure standards
- recognise and prioritise chemical hazards in the workplace
- determine control measures for a particular hazard.

A foundry might provide respiratory protection on its moulding line against silica dust, but fail to appreciate that polyurethane moulds release isocyanate vapours into the workplace atmosphere, vapours that are not captured by a dust mask. The H&S practitioner's knowledge of all the risk factors will be needed to provide correct protection.

2.5.1 HAZARD AND RISK

Hazard and risk are two quite different concepts, although the terms are commonly used interchangeably when talking about hazardous substances. **Hazard** represents the *potential* for a substance to cause adverse effects. A hazardous substance is one which has sufficient toxicity to cause harm, given the appropriate conditions of exposure or absorption. **Risk** is a function of the *likelihood* of an adverse effect occurring in a particular situation and of the *magnitude* of the adverse effect (the severity of the outcome). If a hazardous substance is to cause harm, the worker must be exposed to a sufficiently large amount of the substance.

There are hundreds, even thousands, of substances in workplaces with the potential to cause harm. However, it is important to differentiate between potential hazards and those hazards where there is risk of harm. Asbestos in an asbestos cement sheet is a hazard, but may not be a serious risk because the likelihood of an inhalation exposure occurring is very low if the material is not machined or abraded. However, asbestos fibres released into the workplace air during removal of asbestos lagging will almost certainly result in an inhalation exposure leading to a higher risk of toxic effect. Benzene is a potent leukaemia hazard but while contained in a closed reaction vessel presents a low risk; xylene used in open tanks or in painted coatings may be a greater risk to health.

In mathematical terms, risk is a function of consequence or severity and likelihood. Likelihood is related to the extent of exposure, with greater exposures more likely to result in injury or disease.

$$\text{RISK is proportional to HAZARD} \times \text{EXPOSURE} \quad \text{or } R \propto H \times E \qquad \text{(Equation 2.1)}$$

If exposure is zero (exposure is controlled), then risk will also be zero and risk is controlled. (Chapter 4, Control of Workplace Health Hazards, examines a number of ways to control exposure.) However, if a hazardous material can be replaced with a non-hazardous material (e.g. replacing a solvent process with a water-based one), then exposure may not need any control.

A quote to remember:

> *All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy.* Paracelsus 1493–1541

Paracelsus' remark summarises one of the fundamental principles of modern toxicology—the concept of **threshold dose**. That is, doses of substances below the threshold for adverse effect are not harmful, and in fact some chemicals at low doses are beneficial. Essential elements such as cobalt, iron, sodium and calcium testify to the power of this observation. Doses exceeding the threshold dose will give rise to adverse effects.

2.5.2 ABSORPTION OF HAZARDOUS SUBSTANCES

For materials to be able to exert a toxic effect, they must have a **route of entry** into the body. In the work situation, we are generally concerned with only three routes of entry:

- inhalation
- skin contact
- ingestion.

Inhalation of a dust, fume, vapour, mist or gas is the major route of absorption in the work environment. The membranes lining the lungs provide a large area (approximately 140 m^2) across which materials may be absorbed. Unless provided with special breathing apparatus, people must maintain constant contact with the air of the workplace to survive.

The physical nature of many workplace substances determines that they evaporate or become airborne and so contaminate the air. For this reason, a large part of hazardous substance control is based on keeping the work atmosphere clean. This is why exposure standards, discussed in Chapter 3, relate specifically to inhalation of airborne substances. It is also why occupational health and hygiene investigations often focus on material which can be inhaled.

Skin contact is the second most important route of absorption. The adult body has a skin surface area of about 2 m^2. Entry through the skin applies most frequently to liquids, and some materials (e.g. oils and some pesticides) enter predominantly via the skin. Sometimes materials encountered as vapours or gases also enter through the skin, resulting in significant absorption and distribution through the body. Occasionally, substances will enter the body through both the lungs and the skin (e.g. mercury and hydrogen cyanide). Of course there are also substances that exhibit direct skin effects. These include corrosives (acids), alkalis and other materials (e.g. arsenic). The eye is also at risk from direct contact, particularly to biohazards and corrosives.

Individual workers vary in their susceptibility to skin penetration. Persons with thicker skin will not be at the same risk as workers with thin skin. Oily skins may provide better protection than dry skins. Some areas of skin are very thin (e.g. scrotum) and provide less of a barrier than thicker skin (e.g. palms). Damaged skin may often present a ready route of entry for a hazardous substance, particularly microbiological hazards. The level of skin hydration, often dependent on work-rate and the extent of perspiration, may also alter barrier characteristics, making the skin more freely permeable to particular chemicals.

Ingestion (swallowing) is a usually minor route of absorption. Good personal hygiene, particularly attention to washing of hands, and avoiding eating, drinking and smoking in the workplace can help reduce this route of entry. Some materials may be swallowed by virtue of internal respiratory clearance mechanisms depositing mucus at the oesophagus, or following deposition of materials in the mouth or pharynx during mouth breathing.

Other absorption routes are rarely encountered, but include direct injection of hazards into the bloodstream or body tissues. These may be relevant to specific workplaces and processes, such as the accidental injection of infective agents from contaminated syringe needles, transdermal injection of fluids from high-pressure hoses, or puncture and laceration injuries from chemically-contaminated laboratory glassware.

2.5.3 TOXIC EFFECTS OF HAZARDOUS SUBSTANCES

In the human body, the different effects and severities of hazardous materials are vast in number. Some of these are examined specifically in later chapters. In simple terms these effects can be described in terms of **where** and **when** they affect the body.

Where:

- **Local effects** are adverse effects on the particular tissue which has been exposed to the hazardous substance. Examples include:
  - corrosives that can severely damage the eyes or skin
  - organic solvents that can induce dermatitis on exposed hands
  - gases (chlorine, ammonia) that can intensely irritate the respiratory tract.

- **Systemic effects** are adverse effects on one of the twelve or so systems of the body after absorption of the hazardous substance. For example:
  - lead affects the nervous system, blood, kidneys and reproductive functions
  - organophosphorus insecticides affect the nervous system.

When:

- **Acute effects** are short lasting and develop during or soon after exposure. These can include irritant, acute poisoning or reproductive effects, for example:
  - gases (e.g. ammonia) immediately irritate the eyes and respiratory tract
  - excessive exposure to toxic organic solvents can induce rapid narcotic effects (e.g. headache, dizziness, incoordination, unconsciousness)
  - high exposure to some metal fumes produces a rapid onset of metal fume fever
  - miscarriage from the acute effect of a substance on the developing foetus.
- **Chronic** indicates that the adverse effects are long lasting, if not permanent. Onset may be soon after exposure, or it may be delayed many years. Some well-known chronic health effects are:
  - asbestosis and silicosis following excessive exposure to asbestos and quartz respectively
  - lung cancer following exposure to dusts containing arsenic
  - chronic dermatitis from exposure to chromium-containing cements
  - lung cancer and mesothelioma from asbestos exposure
  - damage to the DNA structure of sperm and ova, and reduced fertility (suppression of sperm production), for example, from lead exposure.

Information about possible acute and chronic effects should appear on the material safety data sheet (MSDS) for the substance.

The terms 'acute' and 'chronic' may also be used to define the duration of exposure, rather than the duration of the toxic effect. These have been applied specifically to animal toxicity-testing guidelines, such as those specified by the Organization for Economic Cooperation and Development (OECD 1993). The guidelines, as applied to laboratory-bred rats, identify acute studies (single exposures), short-term repeated dose studies (14–28 days), subchronic studies (90 days) and chronic studies (6–30 months). The generally accepted usage of these terms in occupational toxicology relates to short exposures (acute) and exposures of several years (chronic). Hence an acute **exposure** may result in a chronic **effect** (e.g. a high exposure to organophosphorus insecticides may result in delayed neurological impairment that may be long lasting).

2.5.4 THE IMPORTANCE OF DOSE

Earlier we quoted Paracelsus on the dose making the poison. A vital point to remember is that most hazardous substances are foreign to the body; they are not meant to be there. In order to link absorption of hazardous substances and the effects they produce, we have to link the observed effects with the **amount** absorbed stated in precise and measurable terms. It is preferable not to describe toxic doses using relative terms such as low, moderate or high exposure, but to obtain numerical data relating to dose. All the exposure limits given in Chapter 3 are based on **measurable** quantities.

There are two approaches used by toxicologists to examine the relationships between dose and response. The first is where the extent of the effect is related to dose — for example, the degree of enzyme inhibition arising from chemical exposure, or the amount of skin redness (erythema) from UV exposure.

Figure 2.2a shows the dose–effect relationship with arithmetic axes, and Figure 2.2b shows the same data plotted on a logarithmic dose axis. The logarithmic representation shows the classic sigmoid (S-shaped) nature of the dose–effect relationship. The logarithmic axes enabled the linear data between 20 and 80 per cent of maximal effect to be accurately plotted, and the dose causing a 50 per cent maximal effect, the **ED$_{50}$**, to be estimated. Figures 2.2a and 2.2b also show that as dose declines, a smaller effect is observed, until we see a dose at which no effect is seen — the **threshold dose**. These two parameters, the threshold dose and the ED50, together with the slope, define the location and shape of the dose–effect curve.

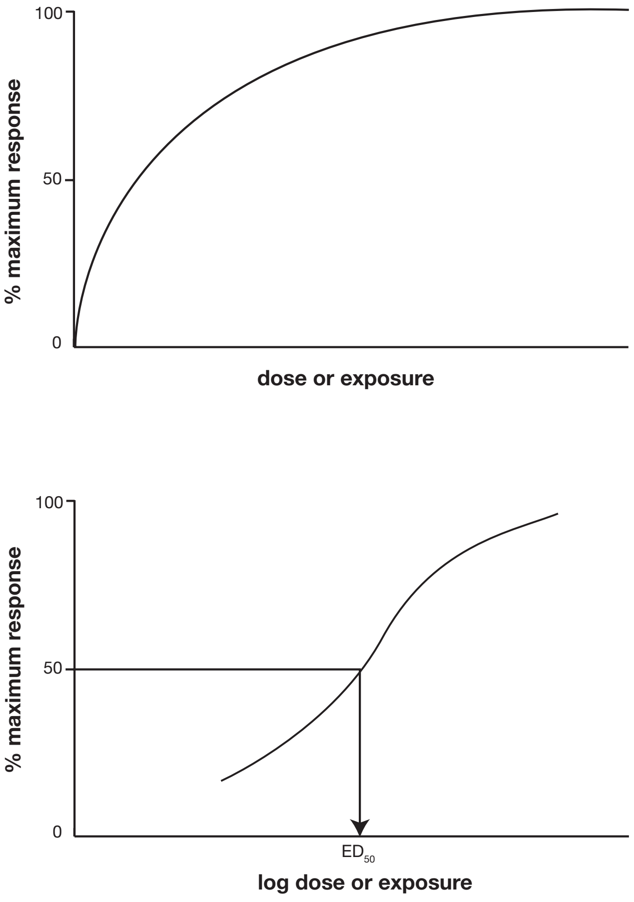

Figure 2.2
Graded dose–response relationships.
(a) linear plot
(b) logarithmic plot

In the second approach a defined response is examined in groups of individuals exposed to a range of doses of chemical. These quantal responses may be the presence or absence of a measurable outcome—for example, at least 10 per cent inhibition of liver activity, or unconsciousness, or death. The proportion of the tested group with this response is plotted against the dose (or more usually log dose, as seen in Figure 2.3). From these data, toxicologists can define terms such as **ED$_{50}$** or **LD$_{50}$**. These are the doses causing, respectively, the defined outcome or death in 50 per cent of the exposed population. Note that the subscripted position of the numerals in the expression indicates that this refers to population data rather than the graded dose–effect described earlier.

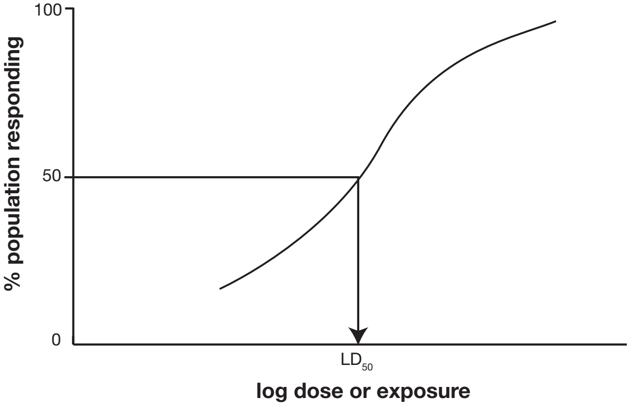

Figure 2.3
Quantal dose–response relationship

The LD$_{50}$ and related estimates are useful quantifiable concepts because they incorporate a measured dose and a measured rate of morbidity (sickness) or mortality. They represent estimates of the relative toxicity of materials by which we may compare substances encountered in the workplace. For example, the approximate LD$_{50}$ of ethanol is 10 000 mg per kilogram body weight, whereas those of DDT and dioxin are 100 and 0.01 mg/kg respectively.

2.5.5 THRESHOLD VERSUS NON-THRESHOLD EFFECTS

So far we have considered the proposition that as dose declines, the effect seen or the proportion of the population affected also declines, and that there is a threshold dose below which no effect is seen. This threshold, even if derived from animal experiments, can be used to derive tolerable intakes of chemicals (TI), acceptable daily intakes (ADI) or reference doses (RfD). These are usually obtained by incorporating safety factors into the data based on interspecies differences (extrapolating from animals to humans), interindividual differences (accounting for different sensitivities of individuals of the same species), the severity of the effect observed, etc. Thus the safety factor provides a conservative estimate of the **safe dose**. This method is usually sufficient for risk assessments of most chemical exposures.

An alternative approach suggests that at every dose above zero there is a probability (or risk) of an adverse effect. This non-threshold approach is often applied to carcinogen exposures. For example, cancer may occur in 1 individual per 1000 with a given exposure. Reducing exposure by a factor of 100 may reduce the cancer rate to 1/10 000. Reducing exposure further may result in 1 cancer per million exposed, and so on. In these cases, an acceptable risk is defined (e.g. 1 per 100 000) which may be used as the basis for exposure standards for carcinogens, radiation and other hazards thought not to have a threshold. A more detailed examination of occupational carcinogens has been published by the Australian Faculty of Occupational Medicine (AFOM 2003).

2.5.6 FURTHER EXAMINATION OF DOSE

The dose of a hazardous substance is the amount absorbed, which takes into account both the concentration and duration of exposure. Dose might be expressed by the equation:

$$\text{DOSE} = \text{Concentration of exposure} \times \text{Duration of exposure} \qquad \text{(Equation 2.2)}$$

This equation disguises a few oversimplifications. For example:

- the dose may be less than the amount inhaled if most is exhaled without any absorption (e.g. many gases)
- workers with heavy workloads breathe more air than those with light workloads and so have larger doses
- dose may depend on whether the worker is a mouth- or nose-breather
- additional exposure may come from non-occupational sources (e.g. carbon monoxide from cigarette smoking).

Clearly, if we can reduce either the concentration *or* the duration of exposure, we will reduce the actual dose. Exposure standards take both of these factors into account. Our attempts to develop safe levels for exposure standards are often based on dose studies in the workplace, volunteer studies or animal studies where various effects (even disease and death) have been identified. Acceptable or safe levels of exposure have been proposed following comparative studies of exposures where injurious effects were observed and those where none were observed.

The dose–response curve shows that there are some **susceptible** individuals, the ones who succumb at low concentrations. There are also some **highly resistant** individuals who don't succumb at high exposure, and **average** individuals somewhere in the middle.

Figure 2.4 indicates stylistically the variability of these susceptible, average and resistant individuals in their response to differing doses. The *y*-axis shows relative effect, in increasing severity. The zone marked 'normality' indicates no response, 'adaptation' indicates that there are cellular, biochemical or physiological changes but these are not considered adverse, while 'disease' indicates that changes in function are adverse effects compromising the health of the individual.

Susceptible individuals exhibit more severe responses, such as disease or death at doses lower than average.

Resistant individuals exhibit no response, or may adapt with higher doses and may also tolerate much higher doses without disease or death.

Our determination of safe dose in general must be based on the most susceptible individuals in the working community. Exposure standards thus tend to be based on doses tolerated by 'average' subjects without ill effect. That is, they are designed to protect nearly all workers. There may, however, be hypersensitive individuals, for example those with a pre-existing disease, who may suffer adverse effects at doses lower than the rest of the population.

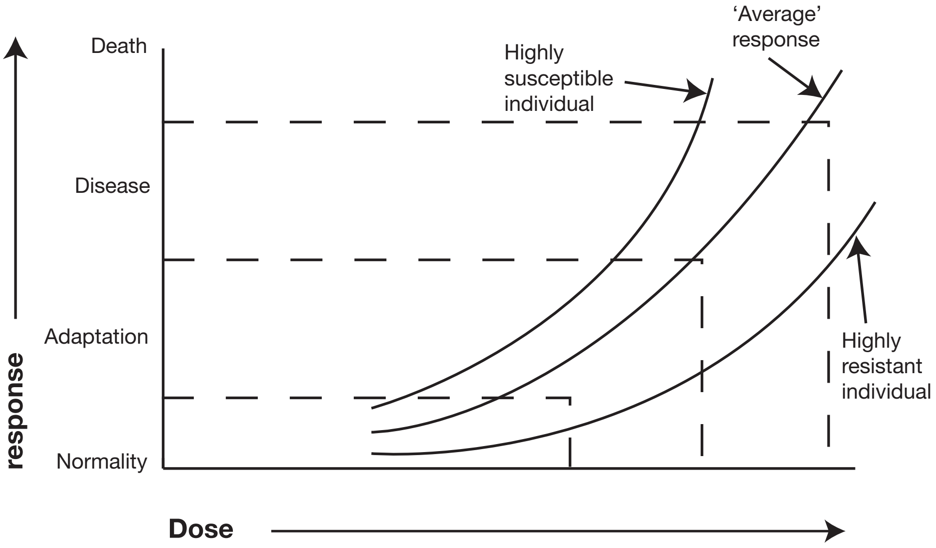

Figure 2.4 Variability of human exposure to dose

2.5.7 THE ALARP PRINCIPLE

As an H&S practitioner, one should always endeavour to reduce the exposure of the worker to As Low As Reasonably Practicable (ALARP).

This means that if it is practicable to reduce the exposure (i.e. the dose) of the worker, you should do so. Practicability takes into account the technological means of control at your disposal, physical limitations, any added health benefits and economic cost factors.

For example, hospitals use the anaesthetic nitrous oxide. Operating staff are exposed to anaesthetic gas at about 70 ppm (parts per million) when it is exhaled by the patient. Although the exposure standard for nitrous oxide is 25 ppm, concentrations in the workplace can be reduced to 20 ppm by increasing cross-flow ventilation, or to less than 1 ppm by using a proper scavenging mask on the patient. The choice of scavenging masks is good practice, easily achievable, economic and consistent with the ALARP principle.

At work, the H&S practitioner will be required to make decisions on three types of exposure:

- Regular exposures which lie below the recommended exposure standards. Here the dose (exposure × time) is likely to be within acceptable limits and the risk is low. Nonetheless, you should still aim to reduce exposure to ALARP.
- Uncontrolled, gross overexposures can result from an accident, from loss of control procedures, or from exceedingly poor hygiene practice—for example, the bursting of an organic solvent delivery line, or entry into a confined space such as a vapour degreaser. Where practicable, even in emergency situations, procedures must be available to limit exposure to ALARP.
- Known operations producing significant exposures which could exceed exposure standards and hence exceed a safe dose—for example, applying toluene di-isocyanate-based polyurethane cork floor sealant for 30 minutes each day without proper respiratory protection. Even though the exposure is relatively short, the risk is potentially great, so control needs to be based on ALARP.

You should always consider the ALARP principle to minimise risk further. Good basic controls to prevent exposure embody the ALARP concept, because practical technical measures are readily available to control most work exposures. ALARP does not imply relentless pursuit of the reduction of exposure (e.g. exhaust ventilation and respiratory protection), although some special high-risk industries demand this approach.

2.5.8 THE CONCEPT OF HAZARD, RISK AND DOSE FOR PHYSICAL AGENTS

Not all workplace health hazards involve toxic substances. Significant health hazards are also posed by physical agents. Energy from physical hazards is absorbed by various sense organs and by the body itself. Noise, heat and radiation, for example, are all very commonly encountered health hazards. For each of these the strict definition of a toxic substance does not apply. However, the concept of risk being a function of exposure and consequence is equally applicable to effects of energy absorption from physical hazards.

2.6 CLASSIFICATION OF WORKPLACE HEALTH HAZARDS

This book presents to the H&S practitioner some basics in occupational health and hygiene in the following areas only:

- chemical hazards (Chapters 5, 6 and 7)
- principles of biological monitoring (Chapter 8)
- indoor air quality (Chapter 9)
- physical agents (Chapters 10, 11 and 12)
- biological hazards (Chapter 13).

The book does not attempt to deal with workplace ergonomics, stress-related disorders or psychosocial effects related to work. These are large areas of study, each of them sufficient to require separate treatment. The H&S practitioner should consult other texts for assistance in these specialist areas.

2.6.1 CHEMICAL HAZARDS

Chemicals give rise to the greatest number of hazards to workplace health. The category 'chemicals' includes many naturally-occurring substances, such as minerals and cotton, as well as both simple and complex manufactured chemical products. Chemical exposure can arise through direct use or from by-products.

Exposure to chemical hazards occurs in the following ways:

- Inhalation of airborne contaminants, including:
  - dusts—silica, coal, asbestos, lead, cotton, wood, cement
  - mists—acid mists, chrome plating
  - gases—chlorine, sulphur dioxide, ethylene oxide, ozone
  - fumes—smoke, metal fumes from welding
  - vapours—chlorinated and aromatic solvents, amines, ethers, alcohols
- Through skin contact, including:
  - direct absorption through skin—pesticides, phenol
  - action on eye and mucous membranes—acids, irritating effect of vapours
  - corrosive action on the skin—acids, alkalis, phenols
  - solvent defatting of skin—toluene, methylene chloride
  - photosensitising agent to skin—creosote, bitumens
  - allergenic action on skin—nickel, chromium.

2.6.2 PHYSICAL AGENTS

All workplaces result in exposure to physical agents which could be harmful, including heat, noise, vibration, repetitive movements, light and other radiation. Increasing mechanisation may decrease heat stress, but increases in industrialisation and greater use of high technology can be accompanied by new hazards. Health effects are caused by:

- noise—absorbed though the ear; some very low frequency (infrasound) and ultrasonic sounds are absorbed directly by the body
- vibration—received by body in contact with vibration
- light—visible, ultraviolet and infrared are received by both the eye and the skin; the eye is susceptible to laser energy; poor lighting may also be a workplace health hazard
- heat—absorbed by all parts of the body
- cold—cold environments experienced by whole of body; extremities in contact with cold
- pressure—extremes affect areas of body with gas spaces: lungs, teeth, sinuses, inner ear

- electromagnetic non-ionising radiation—microwaves, radiofrequency and very low electromagnetic radiation are received directly by the body
- ionising radiation—X-rays, radioactive decay energies: α (alpha) particles, β (beta) particles and γ (gamma) rays are received directly by the body.

Physical agents and their health effects in the workplace are discussed in detail in Chapters 10–12.

2.6.3 BIOLOGICAL HAZARDS

Some workers are subject to health hazards relating to work with biological materials or from working in environments where micro-organisms may abound. These hazards may arise from animal or plant materials, or sometimes the handling or treatment of sick persons. A few biological hazards (e.g. *Legionella*) exist more widely and affect members of the general working community. Chapter 13 looks at some of the biological or microbiological hazards of workplaces under the following classes:

- bacterial—*Legionella*, *Brucella*, tuberculosis, Q-fever, etc.
- fungal—infective agents (e.g. tinea); allergenic agents (e.g. *Aspergillus*)
- viral—hepatitis B, HIV (AIDS).

2.7 OCCUPATIONAL EPIDEMIOLOGY

Not all the activities of the H&S practitioner will be preventative. You may need to investigate how ill health has arisen. Sometimes the cause will be easy to recognise, particularly for hazards with well-known acute effects. If you found that older workers in a silk-screen department seemed extraordinarily clumsy, when their experience would suggest they were capable of great care in their craft, you might investigate the extent of their solvent exposure. Other investigations may be more difficult to carry out. If you find, for example, that none of the 15 men working in a pesticide synthesising plant have any children, you may need to investigate their occupational exposures. Such problem situations may be the starting point for epidemiological investigations.

We have imperfect knowledge of the health outcomes associated with our industrial use of hazardous substances, with new information on the health risks of substances and processes regularly coming to light. In the workplace, this field of study is known as occupational epidemiology.

The study of **disease distributions and their determinants** in worker populations constitutes the science of occupational epidemiology, and is a topic beyond the immediate reach of most H&S practitioners. Epidemiological studies tend to be medically and statistically complex. They often require large administrative resources to conduct and large sample populations to investigate.

However, while these occupational epidemiological studies have often been disparagingly referred to as 'counting dead bodies', reflection indicates they are far more than that. They underpin much preventive health in the workplace, and some exposure standards are based on extensive epidemiological studies.

The H&S practitioner should be familiar with some occupational epidemiological concepts, which may help them to draw more guarded conclusions from meagre or unrelated facts. These concepts may guide the H&S practitioner to put together the information vital for valid studies in an accessible form. The data may include:

- identification of the population at risk, numbers, dates of birth, gender, etc.
- when each worker commenced and ceased employment
- complete employment histories
- nature of jobs
- hazardous agent exposure
- medical or accident records held by employers
- details of workers' compensation claims
- smoking and possibly alcohol history for each worker.

One of the shortcomings of the majority of epidemiological studies conducted in the workplace is that there are either no or inadequate data on the exposures of the population under study.

2.7.1 WHY CARRY OUT EPIDEMIOLOGICAL STUDIES?

The purpose of epidemiological studies is to find out whether there is an association between exposure and ill health so that appropriate action can be taken. For example, the association between mesothelioma and blue asbestos exposure has been well demonstrated. The association is so strong and the outcome so unequivocal that use of asbestos is now prohibited by law. Likewise, the increased rates of aplastic anaemia and leukaemia among workers exposed to benzene, compared with the general population, led to restrictive legislation, reduction in exposure and substitution by far less toxic solvents.

But dramatic links such as these between occurrence and cause are not always evident. Many, and probably most, studies suffer from deficiencies and limitations. Confounding factors, bias and poor data often prevent firm conclusions being drawn. Old, unverifiable clinical observations may be incorrect and workplace histories may be incomplete. The signal becomes lost in the noise, the findings are equivocal.

Despite these shortcomings, occupational epidemiology often provides the only valid way to establish the health hazards associated with many substances and processes.

2.7.2 HOW ARE THESE STUDIES CONDUCTED?

Two epidemiologic approaches commonly employed are:

- Observational studies—for example, ecological, cross-sectional, case-control, longitudinal or cohort studies
- Experimental studies—for example, randomised controlled trials, field trials or community trials.

Since nearly all occupational epidemiology studies are observational studies we will not deal further here with experimental studies. The observational studies can be described in order of methodological strength as follows:

2.7.2.1 Cohort studies

This type of study has several characteristics:

- a known group of workers
- a fixed time period of study
- some knowledge of exposure to the agent under investigation.

The known group of workers may all be involved in a process at a particular factory (e.g. viscose rayon workers handling carbon disulphide), or an industry-wide grouping (e.g. all workers involved in vinyl chloride manufacture in the country). These groups usually have to be fairly large in number, several hundred or more.

The time period may be from some point in the past up to the present, in which case the cohort under investigation is called a historical cohort. Such studies are called **retrospective** studies. If the time period starts now and runs into the future, it is called a **prospective** study.

Knowledge of exposure to the agent requires hygiene measurement data. If this is not available, the surrogate 'years of exposure' is often used, in which years of exposure are split up into several classes: 1–5 years, 6–10 years, 11–15 years, etc.

Retrospective studies are comparatively cheap; however, there is little or no control over data available. Complete identification of the study population and obtaining all job and smoking histories is often problematic. The linking of subjects identified from company files to state and territory cancer registry records is difficult and likely to be incomplete. Prospective studies are normally more expensive, and may take 10 to 20 years to complete, but data on the cohort are easier to assemble.

One other vital piece of information is required in these studies, a group to use as a yardstick. This comparison group is called the control population. The control group should differ only in the fact that it has not experienced the exposure of interest. For example, when investigating the health effects of foundry work, the population under investigation cannot be compared with other foundry workers. In the investigation of benzene exposure the health of refinery workers exposed to benzene can be compared with the health of those not exposed, etc. General population statistics are often used as the control, but special groups can be constructed when required. Many studies can have considerable difficulties in matching the control group to the study group in age distribution.

These studies express findings as measured of morbidity (e.g. a particular illness) in the group, or of mortality (death) rates, often using death certificate registry information in the latter case. The **relative rate** is expressed as a ratio, such as Equation 2.3.

The comparison is made as follows:

Standardised mortality ratio (SMR)

$$= \frac{\text{observed number of deaths in the study group} \times 100}{\text{expected number of deaths in a control population}} \qquad \text{(Equation 2.3)}$$

An SMR of 100 shows that the population under investigation is dying at the same rate as the comparison population. A higher SMR shows that the population under investigation has a higher rate of mortality than the comparison population.

Industrial populations often have a low SMR. This is known as the **healthy worker effect**. The healthy worker effect arises because on average workers are in better health than the general population for two reasons: firstly, because the general population includes people unable to work because of ill health, and secondly, because workers who suffer ill health tend to leave work.

To express risk in cohort studies we need to establish which subjects had experienced the exposure of interest and then identify the proportion of the exposed and unexposed subjects who had experienced the health outcome of interest. A simple example involving numbers of persons suffering from renal failure is given in Table 2.1.

Table 2.1 Schematic showing proportions of a cohort displaying presence or absence of renal disease associated with cadmium exposure

	Renal failure	No renal failure	Total
Cadmium exposure	a	b	a + b
No cadmium exposure	c	d	c + d
Total	a + c	b + d	

The probability of an exposed person in a cohort study of developing renal failure associated with cadmium exposure compared with the probability of renal failure in non-exposed persons is given by Equation 2.4.

$$\text{Relative risk} = a/(a + b) \div c/(c + d) \qquad \text{(Equation 2.4)}$$

2.7.2.2 Case-control studies

A case-control study takes a different approach. It comprises:

- a group of patients or workers with a particular disease, and
- a control group which does not have that particular disease.

The exposure history of the cases and controls are then compared. It is possible that some cases and some controls will have had exposure to the agent under study. Being able to reach valid inferences depends on how well the exposure/non-exposure histories are recorded. The method is useful to investigate rare diseases, because investigators can work with small numbers. To investigate rare diseases with a cohort study would require large numbers of participants and would consequently be very expensive.

In case-control studies epidemiologists use the measure called the **odds ratio**, which is given by Equation 2.5 using the example in Table 2.1.

$$\text{Odds ratio} = ad \div bc \qquad \text{(Equation 2.5)}$$

This is a ratio of the odds of exposure among the cases, to the odds in favour of exposure among the controls. For relatively rare diseases, the relative risk calculated in a cohort study and the odds ratio in a case-control study are approximately the same.

2.7.2.3 Cross-sectional studies

These studies are generally undertaken at a 'point in time' or over a relatively short period of time. They comprise a snapshot of the health and exposure of a particular group. As a result causation is difficult to determine, because it is not possible to determine whether the exposure preceded or followed the disease. A major limitation of these studies is the possible influence of a survivor effect. For instance, a cross-sectional study investigating the prevalence of asthma in a dusty industry may result in a 'low prevalence' being reported, concluding that the dust exposure is not related to asthma. However, it may be the case that the heavily exposed workers that suffered asthma left the industry before the study was conducted. Only those remaining took part in the study, and these workers were predominantly non-diseased.

Cross-sectional studies are inexpensive and may be done quickly and easily. They are useful as a first step to a suspected cause if many exposures are present in a workplace.

2.7.2.4 Ecological studies

Ecological or correlational studies are considered 'hypothesis generating' studies. They involve the analysis of the health and exposures of groups or populations, not at the individual level, and so the link between exposure and disease cannot be made. An example of an ecological study would be the observation that population A smokes more than population B and has higher rates of heart disease. We do not know, but we might suspect, that the smokers are the ones with the higher rate of heart disease. Ecological studies can be inexpensive and simple to conduct as they often rely on data sources collected for other purposes, such as compensation databases, cancer registers or hospital records. These studies can easily be biased due to various socioeconomic factors not having been recorded. They are considered the weakest study design, but are often initiated due to their low cost and quick results.

2.7.3 A FEW RELEVANT EPIDEMIOLOGICAL TERMS

Rates Epidemiological studies talk in terms of **incidence rate** or **prevalence rate**. Incidence is the rate of new cases appearing in the population during a certain time period. This may be 10, 5 or 2 new cases per 1000 people at risk per year. Incidence is crucial for studying changes in rate of appearance of a disease. Prevalence relates to whether the pool of cases is growing or shrinking.

The prevalence is the total number of cases in the population at any point in time. Figure 2.5 allows us to appreciate prevalence as the result of both incidence and loss. A cross-sectional study at a particular point in time will yield a point prevalence. When a study is conducted over a particular time span, it can produce a period prevalence. Cross-sectional studies are often called 'prevalence studies' because they can only measure the prevalence and not the incidence of a disease.

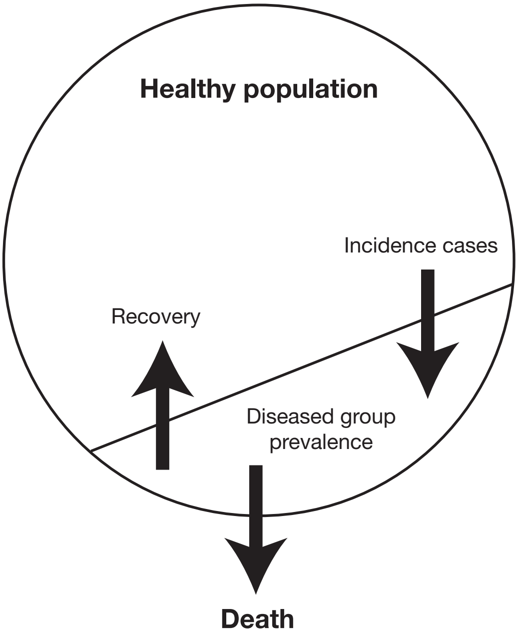

Figure 2.5 Diagram indicating the difference between incidence and prevalence

Bias All studies suffer from bias. Indeed, criticism of studies on the grounds of biased data seems an occupational hazard for the epidemiologist. Bias can occur in the selection of the group to study, the control group, in interpreting data, in questionnaire responses, healthy and unhealthy worker effects, mismatching of age distributions, survivor effects, loss to follow-up, subjective assessments, confounders such as the effects of smoking, etc.

Statistical significance Epidemiological studies always refer to statistical significance in their findings. That is, the epidemiologist estimates the probability that the association between the exposure and the outcome is by chance. This is done because a random outcome is not a good basis for any health prediction or future action on control.

For example, the study might be looking at bladder cancer incidence among rubber workers. The epidemiologist attempts to attach some degree of confidence to the findings. A whole range of statistical methods are available for numerical testing of various hypotheses, but the tests generally all seek one common goal—that is, to be 95 per cent confident, or better, that the observations were *not* due to chance; in other words, there is less than a 1 in 20 chance that this is a random association. This is sometimes described as 'statistically significant at $p < 0.05$'.

If the study results are described as statistically significant, this means that the variation in disease rates between the study and control populations is unlikely to be by chance alone.

For example, a study which shows an SMR of 300 (18 deaths were found when only 6 were expected) might be able to quote its findings as statistically significant if the lower 95 per cent confidence limit is greater than 100.

2.7.4 PRACTICAL SIGNIFICANCE

Despite the obvious difficulties in occupational epidemiology, this field of study provides the surest basis for long-range improvements in preventive occupational health. Such studies have provided much of the information we have to date on rare disease occurrence and causative exposure. The H&S practitioner should thus always be receptive to the possibility that workplace factors may be implicated, while resisting the temptation to blame every illness on workplace exposures.

2.8 CONCLUSIONS

Section 2.3 introduced some of the issues associated with establishing cause in respect of workplace chemical exposures and disease. In particular, if a worker has symptoms, how can they be confidently attributed to the workplace as a cause? With your understanding of basic toxicology and epidemiology, you may now be in a position to suggest a causal relationship if there are data, observations or published evidence to support the following:

- Gradients exist in space. That is, those workers remote from the source of a pollutant responsible for disease have low rates of symptoms, those near the source have high rates of symptoms and those between have intermediate rates of symptoms.
- Distribution of cause reflects distribution of response. For example, workers at similar industrial plants without the proposed cause do not display symptoms.
- Time sequences are observed—for example, symptoms occur after exposure.
- Results are consistent with other published studies.
- The proposed mechanism for the effect is plausible.
- Experimental evidence (e.g. animal studies, human exposure studies) support the results.
- Preventive trials or interventions reduce the effects.

In addition, we may combine these questions with others to critically evaluate the extent of exposures and the veracity of symptom reports. These questions may include:

- Was there a potential for exposure?
- Was the potential exposure level likely to cause symptoms?
- Are symptoms consistent with the suspected agent?
- Are there independent measurable disease/symptom indices?
- Are there independent measures of exposure?

In some cases there may be a clear association between exposure and reported symptoms. In other cases, some of the circumstances above may be met and others not, and the H&S practitioner will need to make a judgment based on the balance of evidence. Experienced hygienists may effectively meet these challenges. However, it is also important to recognise when specialist toxicological, epidemiological or other assistance is required to reach appropriate conclusions.

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3. The concept of the exposure standard

Dr Ian Grayson MAIOH

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3.1 INTRODUCTION

The exposure standard (ES), or the national exposure standard, is one of the most important tools used to help assess the risks associated with a range of workplace hazards. All H&S practitioners will need at least a basic understanding of this pivotal concept. In many workplaces there are likely to be times when workers are exposed to a vapour or a dust or some other contaminant in the air. The ES is a guide to upper levels of exposure to a contaminant for unprotected workers. Relevant workplace measurements of exposure are compared with the ES to determine whether the prevailing exposure is likely to be a risk to health, and whether controls (or additional controls) need to be implemented.

3.2 HOW DID EXPOSURE STANDARDS ARISE?

Hazardous chemicals in the workplace have been encountered since antiquity. But it has really only been since the early 1940s, with major advances in medicine and technology, that there have been significant efforts to quantify the risks of workplace hazard exposures and to develop numerical values for maximum 'allowable' concentrations for atmospheric contaminants in the workplace.

The development of exposure standards first occurred in a systematic way in the United States. The most widely known are the Threshold Limit Values (TLVs®) published by the American Conference of Governmental Industrial Hygienists (ACGIH® 2001; 2006). These standards provide good guidance on the acceptability (or otherwise) of exposures to hazardous substances in an imperfect working world. Many TLV® exposure limits have been derived from epidemiological and clinical studies of industrial workers using a particular substance or performing a particular process. In addition, relevant animal studies have also provided useful information, as have some human volunteer exposure experiments.

In general, TLVs® have received wide acceptance as a workable system of presenting workplace environmental and toxicological data in an understandable way and have formed the basis of or been directly adopted as the legislated occupational exposure standards in many countries throughout the industrialised world. However, users should be aware that some exposure standards may be differently based in different countries and terms such as workplace exposure limit (WEL), *Maximale Arbeitsplatz–Konzentration* (MAK), permissible exposure limit (PEL) and occupational exposure limit (OEL) will have different legal as well as scientific meanings. Direct interchange of these terms must therefore be avoided.

3.3 THE EXPOSURE STANDARD IN AUSTRALIA

Historically, the ACGIH® TLVs® have formed the basis for many of the exposure standards adopted in Australia. From 1990 until its cessation in 2005, the National Occupational Health and Safety Commission (NOHSC) established exposure standards through a technical review of available information followed by social input and eventual endorsement. More recently NOHSC has also adopted some occupational exposure standards from the United Kingdom Health and Safety Executive in a 'fast track' process. That process, now in the hands of the Australian Safety and Compensation Council (ASCC), will undergo further change, as the United Kingdom has drastically minimised the number of exposure standards.

The exposure standards used in Australian workplaces were formerly published in the NOHSC document entitled *Exposure Standards for Atmospheric Contaminants in the Occupational Environment* (NOHSC 1995a) which is available on the ASCC website www.ascc.gov.au. This document states that 'exposure standards represent airborne concentrations of individual chemical substances which, according to current knowledge, should neither impair the health of nor cause undue discomfort to nearly all workers'. Users should note that the updated values of the exposure standards are now found only in the *Hazardous Substances Information System* (HSIS) maintained by the ASCC (2005).

There are three types of standards within the exposure standards framework, and one, or sometimes two, of these standards will apply to almost every substance listed. The most common form of standard is the time weighted average (TWA), while the other two types are the short-term exposure limit (STEL) and the peak limitation.

These three forms of exposure standard are used in different ways in dealing with hazardous substances in the workplace. The original NOHSC publication (NOHSC 1995a) provides the following descriptions:

- **Time weighted average (TWA)**
  'Time weighted average means the average airborne concentration of a particular substance when calculated over a normal 8-hour working day, for a 5-day working week.'

  The TWA is the most common of the exposure standards and, except where a peak limitation has been assigned, virtually all substances listed are assigned a TWA.

- **Short-term exposure limit (STEL)**
  'Short-term exposure limit means a 15-minute TWA exposure which should not be exceeded at any time during a working day, even if the 8-hour TWA is within the TWA exposure standard. Exposures at 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 at the STEL.'

  A STEL is only assigned to substances with a TWA standard and where there is evidence either from human or animal studies that adverse health effects can be caused by short-term excessive exposures.

- **Peak limitation**
  'Peak limitation means a maximum or peak airborne concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes.'

  A peak limitation is assigned to substances such as corrosives or irritants, which can cause acute health effects after brief high level exposures and where the excursions permitted by a TWA are therefore inappropriate.

3.4 PURPOSE OF THE EXPOSURE STANDARD

Exposure standards are used to ensure that there is adequate control of exposure to hazardous substances in the workplace. They are not precise divisions between acceptable and unacceptable working conditions but are believed to represent concentrations to which most workers may be exposed day after day during their working lives without suffering adverse health consequences. In the introduction to the original NOHSC exposure standards document (NOHSC 1995a) it is clearly stated that the standards do not represent 'no-effect' levels which guarantee protection to every worker. This recognises that a small proportion of workers may suffer discomfort, or may experience health effects, at or below the ES. Therefore every effort should be made to maintain workplace exposures as far below the ES as is reasonably practicable.

Exposure standards have only been assigned for about 700 of the more commonly used and better studied workplace hazardous substances. Most substances used in workplaces do not have an ES. It is important to recognise that the lack of an ES does not mean that a chemical is safe or will not cause adverse health effects if exposure is sufficiently high. Consequently it is good policy (and a responsibility under occupational health and safety legislation) to keep exposures to all substances as low as is practicable regardless of whether or not they have an ES.

3.4.1 SOME EXAMPLES OF EXPOSURE STANDARDS

Exposure standards have been assigned for gases, organic solvents, metals, pesticides, minerals and naturally occurring products such as wood and grain dusts. Table 3.1 gives examples for some commonly encountered workplace hazardous substances.

Table 3.1 Some examples of exposure standards

Substance	Exposure standard (TWA)
Carbon monoxide	30 ppm (parts per million)
Acetone	500 ppm
Quartz (respirable fraction)	0.1 mg/m^3
Synthetic mineral fibres (SMF)	0.5 fibres/ml
Isocyanates, all (as -NCO)	0.02 mg/m^3

These examples demonstrate that while the numerical values of the exposure standards are all expressions of the concentration of the contaminant in air, they are expressed in a range of different units of measurement. Use of the correct units is vital when comparing measurements with the relevant ES. We will consider these examples in a little more detail.

Carbon monoxide is a toxic gas which is emitted from motor vehicle exhaust. Its units of measurement are parts per million (that is, volume of contaminant per million volumes of air), usually shortened to ppm.

The widely used industrial solvent acetone is a low boiling point liquid which readily evaporates to form a vapour. Its units of measurement are also parts per million, which is the volume of evaporated solvent vapour per million volumes of air.

The ES for quartz dust specifically refers to the 'respirable fraction' of the dust which is the proportion of very small particles that can penetrate deep into the lungs. Its units are presented as a weight (milligrams) per volume (1 m^3) of air. This weight is a very small amount of dust in a relatively large volume of air.

The synthetic mineral fibres ES is in units of the number of fibres per volume of air, but this time the reference volume of air is a millilitre.

Isocyanates are widely used in making polyurethanes and in the spray painting industry and are potent sensitisers. This ES refers only to the chemically active isocyanate part of the chemical (written -NCO) and is expressed as a weight of the functional isocyanate group only per volume (m^3) of air. Once again this is a tiny amount of chemical in a relatively large volume of air; this low standard is aimed at preventing sensitisation in exposed workers.

Most exposure standards are expressed in units of concentration (C) of either milligrams of substance per cubic metre (mg/m^3) or parts per million (ppm). These units may be converted from one to the other using the following formula:

$$C \text{ (in mg/m}^3\text{)} = \frac{\text{(molecular weight of substance)} \times C \text{ (in ppm)}}{24.4} \qquad \text{(Equation 3.1)}$$

As the volume of air varies with temperature and pressure, the above formula assumes that 'standard conditions' of 25°C and 1 atmosphere pressure (101.3 kPa) apply.

In addition to the numerical ES, there is often a good deal of other useful information about the health hazards associated with many of the substances listed. This extra information may include such things as the carcinogen category for the substance or a notice indicating that the substance may be absorbed through the skin or is a sensitiser. The guidance material in the current HSIS exposure standards data set still refers to the original NOHSC exposure standards document (NOHSC 1995a) which provides the following guidance about this extra information:

- **Carcinogens**
  Category 1 carcinogens are established human carcinogens for which there is sufficient evidence of a causal association between human exposure to these substances and the development of cancer;
  Category 2 carcinogens are probable human carcinogens for which there is sufficient evidence to provide a strong presumption that human exposure might result in the development of cancer. This evidence is generally based on long-term animal studies, limited epidemiological evidence or other relevant information.
  Category 3 carcinogens are substances suspected of having carcinogenic potential in humans but where the available information is not adequate to make a satisfactory assessment. There is some evidence from appropriate animal or epidemiological studies but this is insufficient to place the substance in Category 2.

- **Skin notation (Sk)**
  'This notation is assigned to chemicals where absorption through the skin may be a significant source of exposure.' Note that the skin notation does NOT mean that the substance may cause physical damage to the skin such as defatting or corrosive effects.
- **Sensitiser notation (Sen)**
  'Sensitisers are substances which can cause a specific immune response in some people.' This designation indicates that caution should be exercised in the use of such substances to prevent sensitisation in susceptible individuals.

For a limited number of defined high-risk substances there is no numerical ES provided in the NOHSC document. Such substances are either:

- potent established or probable human carcinogens, for which it is not currently possible to assign an exposure standard, or
- simple asphyxiants which in high concentrations may displace oxygen.

Exposure to carcinogens which do not have an ES must be strictly controlled to the lowest practicable level; biological monitoring may be a more reliable indicator of possible exposure. Airborne levels of simple asphyxiants need to be controlled to ensure that an oxygen concentration of at least 19.5 per cent is maintained. It is worth noting that some asphyxiants, such as methane or acetylene, also present an explosion hazard which must be considered when implementing controls.

3.5 SAMPLING IN THE BREATHING ZONE

Within the workplace, two kinds of measurements can be made for atmospheric contaminants:

- static measurements, which are taken in a fixed location such as in the middle of a room or next to a machine, and
- personal measurements, which are taken in the breathing zone of a worker.

Exposure standards should be compared only with the actual exposure workers are likely to receive through inhalation (which means the airborne concentration of a substance in the worker's breathing zone as determined by personal monitoring). The breathing zone (see Figure 3.1) is described by a hemisphere of 300 mm radius extending in front of a person's face and measured from the midpoint of an imaginary line joining the ears.

While static samples taken at a fixed point may be useful in assessing the effectiveness of control measures, or in warning of leaks or fugitive emissions from equipment, they do not provide a valid indication of actual worker exposure.

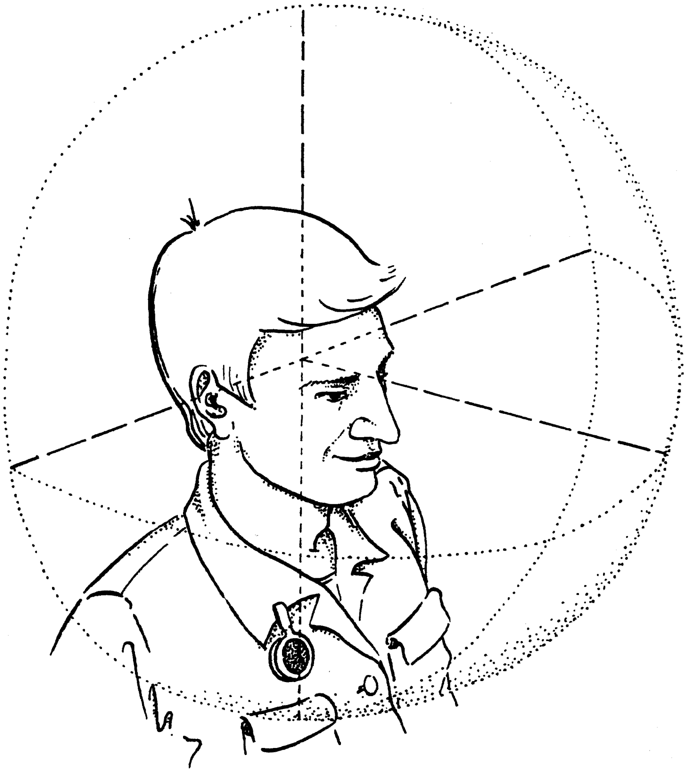

Figure 3.1 The breathing zone—a hemisphere of 300 mm radius extending in front of the face measured from the midpoint of an imaginary line joining the ears
(Reproduced from the 'Code of Practice for Hazardous Substances' No. 24 published by the Victorian WorkCover Authority on 1 June 2000. For further information or updates on this reference see the Victorian WorkCover Authority website <www.workcover.vic.gov.au>.

3.6 PRACTICAL LIMITATIONS OF EXPOSURE STANDARDS

While the ES listings and the supporting documentation provide a range of useful information, there are a number of practical limitations to using exposure standards. These include:

- *Exposure standards do not represent 'no effect' levels which guarantee protection for all workers.* While exposure standards are designed to protect nearly all workers, it is inevitable that biological variation and the range of individual susceptibilities in the working population will result in a small proportion of those exposed at or below the ES experiencing some effects. Persons who have become sensitised to a particular chemical will almost certainly suffer symptoms, possibly serious, at levels well below the exposure standard for that chemical. The ES for sensitising chemicals is generally aimed at preventing sensitisation but it will not protect those already sensitised.

- *Exposure standards are not intended as fine dividing lines between safe and unsafe working conditions*. Exposure standards are only intended to be compared with appropriate and valid atmospheric monitoring results and to provide guidance about whether the measured exposures are likely to be a risk to the health of the exposed employees.
- *Exposure standards should not be used as a measure of relative toxicity.* The exposure standards for different substances may be established based on different biological effects (such as prevention of liver disease in one case or prevention of nerve damage in another or prevention of irritation in a third) and so it is inappropriate to directly compare the numerical values of two or more exposure standards to determine the relative toxicities of the substances.
- *Exposure standards consider only uptake of the chemical by inhalation and consequently are only valid where significant skin absorption cannot occur*.
- *Exposure standards should not be used as the basis for air quality standards for non-occupational exposures.* Exposure standards have been developed to protect workers who spend a proportion of their time (nominally 40 hours per week) in the work environment. Such standards should therefore not be extrapolated to develop long-term air quality standards which would be expected to protect all members of the general population, including infants and the elderly and infirm, who may be potentially exposed to an atmospheric contaminant all day, every day, for a lifetime.
- *Interpretation of atmospheric monitoring data by comparison with exposure standards should be performed only by a competent person*. The evaluation of atmospheric monitoring results can be complex and a large number of variables usually need to be considered to confirm the validity of the data. Consequently, only persons with appropriate qualifications, knowledge and experience should evaluate these assessments and interpret the results against the relevant ES.

3.7 WORKPLACE ATMOSPHERIC MONITORING

The main function of the ES is to provide guidance about the likely risk to health following a workplace measurement of contaminant levels in the breathing zone of the worker. The aim of most workplace atmospheric monitoring is to assess whether there is likely to be a risk to the health of workers and ultimately to determine whether the workplace complies with relevant OH&S legislation.

However, appropriate sampling or monitoring of the workplace to provide a measurement which can be compared with the ES is rarely straightforward. Airborne contaminant concentrations may vary markedly depending on a broad range of factors. For example, the number of sources of contaminant release, the rate of contaminant release, the period of exposure, the type and level of maintenance of controls in place, local climatic factors and worker idiosyncrasies will all contribute to variation in the actual exposure of a worker. The profile of exposure levels of the contaminant over time may vary from low to quite high, but the workplace measurements must provide a meaningful estimate of exposure to compare with the ES.

We must be confident that measurements will reflect the typical or overall situation in the workplace. The questions of where and when to collect samples, from whom to collect samples, for how long to sample and how many samples all need to be answered.

Before any measurements are taken, a sound knowledge is required of the nature of the contaminants and the processes involving their generation. H&S practitioners need also to be familiar with the individual tasks performed in order to identify those workers likely to be at risk of significant exposure. The pattern of exposure needs to be determined to decide a sampling program to properly characterise the exposure. This may be a series of short-term (possibly worst-case) measurements or a long-term average or a series of both long-term and short-term measurements. The short-term peak measurement is important if the contaminant has a STEL, while the 8-hour shift average is valuable where TWA measurements are needed.

An initial survey of a small number of strategically selected samples from groups with the highest suspected exposure should allow a decision on whether an exposure problem exists or not. These initial results can then be used to direct future strategies. A wide variation in results or significant fluctuation in the exposure profiles with time may suggest that more detailed monitoring is required. Relatively constant exposures may be compared with the ES with more confidence using a small number of samples. Measured exposures that are well below the ES will generally require only a few samples to be confident that exposures are acceptable, while exposures closer to the ES will require much more detailed monitoring programs to demonstrate compliance with the standard. Note that it is the average or mean result (or more typically the geometric mean) from a series of sampling tests on an individual worker, or on similar operational groups, which are compared with the ES. Each individual sampling result cannot be usefully compared with the ES, nor can a whole worksite average exposure. For example, fettlers or metal dressers in a metal foundry would be classed as a single operational group, as would moulders, metal pourers and so on. Their group averages could be compared with the ES. More detailed guidance on workplace atmospheric monitoring may be obtained from *Simplified Monitoring Strategies*, published by the Australian Institute of Occupational Hygienists (Grantham 2001).

Extensive (and expensive) workplace monitoring surveys are no substitute for implementing and maintaining effective controls to minimise worker exposure. Consequently, it is usually better to put resources into improving or ensuring proper maintenance of controls to keep exposures well below any relevant ES, rather than to collect a large number of samples for confident quantification of exposures that are close to the ES.

3.8 OTHER CONSIDERATIONS

3.8.1 EXCURSION LIMITS

Most exposure standards are expressed as a TWA averaged over an 8-hour working day. During the working day, some excursions above the TWA are permitted as long as such excursions are compensated by equivalent exposures below the TWA.

Where a substance has a STEL, this value is used to provide guidance on permissible short-term exposures, remembering, of course, that compliance must still be achieved with the overall 8-hour TWA. For the many substances that have a TWA, but have not been assigned a STEL, a different approach is used. This approach is not directly health based but relies on observations of variability of airborne contaminant concentrations in industrial situations. Using these guidelines, a process is only considered to be under reasonable control and employee exposure considered acceptable if:

- the overall 8-hour TWA is not exceeded, and
- short-term maximum exposure does not exceed five times the TWA at any time, and
- short-term exposures exceed three times the TWA for no more than 30 minutes in the 8-hour day.

3.8.2 EXTENDED WORK SCHEDULES

By definition, the TWA exposure standards are applied to exposures over an 8-hour working day for a 5-day working week. However, working days longer than 8 hours, and other unusual shift rotations, are common in industry. Where altered work shifts are in operation, the TWA may need to be reduced by a suitable factor to allow for both the longer time a worker is continuously exposed and the reduced recovery period between successive exposures. For example, a normal 8-hour workday provides 16-hour recovery periods between successive exposures for elimination of absorbed contaminants from the body. A 12-hour shift not only gives increased exposure time but allows only a 12-hour recovery period before the next shift. This may result in accumulation of the chemical or its metabolites in the body, which may represent a health risk to the worker. While several mathematical models have been proposed for adjusting exposure standards for altered work shifts, the model recommended by NOHSC (1996a) is the Brief and Scala Model (Brief & Scala 1975). This model has the advantages of involving simple calculations and it is also the most conservative model. The formula used to adjust the TWA is:

$$\text{Adjusted TWA} = \frac{8 \times (24 - \mathbf{h}) \times (\text{8-hour TWA})}{16 \times \mathbf{h}} \qquad \text{(Equation 3.2)}$$

where **h** is the number of hours worked in the day.

Note that no adjustment is required for STEL values or peak limits as the adverse effects due to acute overexposure are already accounted for by the existing limits. Further, there is no upward correction of the TWA when exposure periods or shifts are shorter than 8 hours.

An alternative model considered acceptable by NOHSC is the Pharmacokinetic Model of Hickey and Reist (Hickey & Reist 1977). However, this model requires a good understanding of the toxicology and pharmacokinetics of the substance, is less conservative and requires more involved calculations, so its use is not preferred.

3.8.3 WORKLOAD CONSIDERATIONS

Exposure standards have been established based on normal or typical workloads under normal climatic conditions. Strenuous work, which results in heavier breathing and an increased lung ventilation rate, will also result in an increased uptake of airborne contaminants. Other factors such as work in adverse climatic conditions (e.g. excessive heat or humidity) or work at high altitudes are also likely to result in an increased rate of respiration and potentially higher uptake. In these situations of increased respiratory demand a more conservative approach is likely to be required when comparing atmospheric monitoring results with the ES.

3.8.4 EXPOSURES TO MIXTURES OF SUBSTANCES

Exposure standards almost invariably apply to the airborne concentration of a pure substance. In the real world, however, the working environment is quite likely to contain two or more airborne contaminants and in some cases may contain a complex mixture of many substances. The application of exposure standards in such situations always requires a good knowledge of the toxicology of the substances involved; even with such knowledge, however, the interpretation of results can be fraught with difficulty.

Where there is clear evidence that the health effects associated with each of the contaminants in the workplace air are unrelated and that the mechanisms of action are independent, then each substance may be separately evaluated against its ES to determine if there is likely to be a risk to health. For example, employees in a foundry may be exposed to carbon monoxide, isocyanates and dust in a hot and noisy environment. In such situations, where the hazards all have different effects, each exposure is assessed in isolation and professional judgment will be required to assess the overall risk.

Sometimes, however, simultaneous exposure will occur to two or more chemicals that target the same organ or have the same mechanism. In this situation the overall health effect on the body is likely to be additive, that is, the sum of the individual health effects from each of the substances. An example where additive effects would occur is in the printing industry where 'blanket wash' (which is usually a blend of a number of organic solvents, all of which depress the central nervous system) is used for cleaning printing rollers.

For substances where additive effects occur the following formula is used. Compliance with the overall exposure standard for the mixture occurs when the sum of all elements is less than or equal to 1.

$$\frac{C\,(X)}{ES(X)} + \frac{C\,(Y)\ldots}{ES(Y)\ldots} + \frac{C\,(Z)}{ES(Z)} \leqslant 1 \qquad \text{(Equation 3.3)}$$

where:

C (X), C (Y), …, C (Z) are the measured airborne concentrations of chemicals X, Y, …, Z, and:

ES(X), ES(Y), …, ES(Z) are the exposure standards for chemicals X, Y, …, Z.

Other interactive effects for mixtures of chemicals, such as synergism (where the overall health effect is greater than the sum of the individual effects) or potentiation (where one chemical has no direct effect but increases the adverse effect of another) are possible. In practice, only a very small number of these types of interactions are known. The classic example of a synergistic effect is the increased risk of lung cancer among cigarette smokers who have also been exposed to asbestos.

3.8.5 CHANGES IN EXPOSURE STANDARDS

Exposure standards tend to change regularly because they are (or should be) the subject of regular review to ensure that the standards reflect the current scientific and technical knowledge about the health effects that may occur following exposure to the substance. A general downward trend has occurred over the last 50 years for those substances with published exposure standards. An example of how exposure standards have changed can be illustrated by the solvent n-hexane. Historically the TWA for this chemical was 500 ppm. As the knowledge about the substance grew and it was found that it can cause nerve damage (peripheral neuropathy), the standard was progressively reduced, firstly to 100 ppm, then to 50 ppm and most recently to 20 ppm. The trend of further reductions in exposure standards for many substances is likely to continue in the future.

3.9 ADDITIONAL INFORMATION

More comprehensive information on NOHSC exposure standards can be obtained from the original NOHSC *Documentation of National Exposure Standards* (NOHSC 1996b), the *Hazardous Substances Information System* (ASCC 2005) or the *Documentation of the Threshold Limit Values and Biological Exposure Indices* (ACGIH® 2001). These documents review the evidence used to set the various TWAs, STELs or peak limitations, and provide information on why the exposure standard was chosen for the chemical. Other information such as the chemical structure, the physical properties of the substance and typical uses are also provided in the documentation.

3.10 OTHER EXPOSURE STANDARDS FOR THE WORKPLACE

3.10.1 EXPOSURE STANDARDS FOR PHYSICAL HAZARDS

The main workplace physical hazard with a widely recognised ES is noise. The ES for noise used in Australian workplaces is contained in *National Standard for Occupational Noise* (NOHSC 2000). The standards specified are an 8-hour equivalent continuous A-weighted sound pressure level of 85 dB(A) and a C-weighted peak sound pressure level of 140 dB(C). Refer to Chapter 10, Noise and Vibration, for a discussion of these terms.

The heat stress exposure standard and its comprehensive documentation can be found in *Heat Stress Standard & Documentation Developed for Use in the Australian Environment* (Di Corleto et al. 2003) while guidance on cold stress may be obtained from the ACGIH® (see Cold Stress TLVs® in ACGIH® 2006). Refer to Chapter 12, Other Physical Agents, for detailed discussion.

Exposure standards for ionising radiation in Australia are published by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and are found in the *National Standard for Limiting Occupational Exposure to Ionizing Radiation* (ARPANSA 2002a), which forms part of the Radiation Protection Series of publications.

Guidance on acceptable exposures to non-ionising (radiofrequency) radiation can be obtained from *Radiation Protection Standard: Maximum Exposure Levels to Radiofrequency Fields—3 kHz to 300 GHz* (ARPANSA 2002b). Refer to Chapter 11, Ionising and Non-ionising Radiation, for detailed discussion.

3.10.2 BIOLOGICAL EXPOSURE INDICES

Exposure standards only provide estimates of acceptable exposures to contaminants by inhalation, and are only valid if significant skin absorption does not occur. Biological monitoring provides a means of assessing exposure to a chemical by all routes of absorption, not just inhalation. The NOHSC has adopted biological exposure standards for a very limited number of chemicals in *Guidelines for Health Surveillance* (NOHSC 1995b), while a slightly more expanded list of biological exposure indices is available from the ACGIH® (ACGIH® 2006). Refer to Chapter 8, Biological and Biological-effect Monitoring, for detailed discussion.

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NOHSC: *see* National Occupational Health and Safety Commission.

4. Control of workplace health hazards

Garry Gately FAIOH and Dr David Bromwich FAIOH

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4.1 INTRODUCTION

As we have already seen, there are three fundamental principles in occupational hygiene—**recognition**, **evaluation** and **control** of health hazards. Control of the hazards to health is the most important aspect of the process. Control involves finding ways of reducing the health risks and providing safe conditions. Control may be directed towards control of hazardous substances or control of hazardous environments. Before the H&S practitioner embarks on any control program it is essential that time is taken to fully understand the hazard and:

- how the hazardous situation arises
- what the exposed people are doing when they are exposed
- why they are doing the task
- what the intended outcomes are of the control program or task
- what the impacts on other people nearby are and, importantly
- what the consequences are if the controls are not adequate or fail to protect the worker.

It is the response to the last point above that should be the major motivator to 'get it right first time'. Historically, the failure to control exposures to asbestos dust in Australia has resulted in thousands of deaths. In short, it is important to have a full appreciation of the problem from the outset.

4.2 LEGAL REQUIREMENTS

There are occupational health and safety (OH&S) Acts and Regulations in all states and territories of Australia. Most of these contain requirements for a general duty of care, plus some directives to manage specific chemicals or agents, such as asbestos, silica, lead, carcinogens, etc. In these Acts and Regulations there is a framework under which the obligations of various parties, including both employers and workers, are established. There are obligations of employers towards ensuring the health and safety of their workers by controlling hazards at source. There are also obligations for workers to cooperate with the employer in their own health and safety, plus obligations applying to all traditional safety matters (guarding, electrical, fall prevention, etc.) as well as to the more difficult matters of occupational health and occupational hygiene.

It is not defensible under law to let hazards persist simply because control will be too costly. It is equally indefensible to leave an identified hazard in an uncontrolled state, simply because workers seem prepared to tolerate it. In almost all workplaces there is still room for improvement in the control of hazards.

4.3 CONTROL OF CHEMICAL HAZARDS

In all states, the Hazardous Substances Regulations are based on the NOHSC (now known as Australian Safety and Compensation Council and WorkSafe Australia) model regulations, *The Control of Workplace Hazardous Substances* (1994). These set out the basic obligations of manufacturers, importers and suppliers for providing information to workplaces at which their products are used. Employers also have obligations to provide relevant information on hazardous substances in their workplaces, to assess and control risks, to train staff, to undertake health surveillance and keep records where necessary. There are many published guidelines about the management of hazardous substances that contain useful information on the hierarchy of control, but the optimal control strategy for any workplace will depend on the situation in each workplace. Some additional regulations on asbestos, lead and carcinogens detail specific actions to be taken.

4.3.1 CONTROL CHOICES

When first investigating a problem the H&S practitioner will often collect data relating to exposure. This could be in the form of actual exposure measurements and/or health impact data (e.g. incidence of symptoms or illness). These data will guide the H&S practitioner in establishing the level of controls that is required. Consider the simple example of a worker in a wine cellar who is exposed to carbon monoxide (at a concentration of 200 ppm) from a forklift exhaust. This situation represents a significant risk to the health of the worker, being an exposure greater than 6 times the permitted 8-hour workplace exposure limit of 30 ppm and equivalent to the 15-minute short-term exposure limit of 200 ppm, and it must be remedied. In this workplace situation there are several solutions that could be applied that highlight the major principles of control:

- remove the forklift and shift everything by hand
- use an electric forklift
- use a catalytic converter to convert exhaust carbon monoxide to carbon dioxide (less hazardous)
- provide ventilation to extract away all the exhaust gases
- allow the worker to work for no more than 15 minutes four times a day in the cellar to comply with the published workplace exposure standards
- provide the worker with a respirator to protect against carbon monoxide.

Not all of these options might be possible. For example, the wine casks might not be able to be transported without a forklift, or ventilation is too expensive because the cellar has to be kept at natural ground temperature, or the worker can't wear a respirator because he is a wine taster. Just how the problem will best be solved depends on circumstances, ingenuity, practicalities and economics. As the risk associated with a particular process might change over time (e.g. increased hazardous output), so periodic review of control procedures may be needed. This will ensure they remain effective at all times, as well as being efficient and economical. In all cases simplicity is important. Complicated control systems require ongoing attention (e.g. training, checking, inspections and maintenance) and consequently may more readily fail.

4.3.2 HIERARCHY OF CONTROL PROCEDURES

The example of the wine cellar worker above illustrates some of the main control strategies used in dealing with health hazards. They are, in hierarchical order:

1. Elimination/substitution
2. Engineering controls
3. Administrative controls
4. Personal protective equipment.

OH&S legislation generally mandates this 'hierarchy of control', that is, the highest order control that is practicable must be used. In other words it is not permissible to use administrative controls if elimination or engineering controls can be used and they are practicable.

Removal of the hazard from the workplace solves the problem permanently. But this is rarely achievable. For example, zinc cannot be removed from a galvanising process nor lead from a battery factory, so then the most practical and economic means of control has to be established.

Frequently, two or more control methods have to be used. For example, with traditional abrasive blasting, sand has been replaced by ilmenite and garnet containing very little quartz (elimination/substitution) and operators are equipped with protective suits and air-supplied respiratory protection (personal protective equipment).

The choice of control recommended by the H&S practitioner will require consideration of:

- the hazard and the extent of the risk it poses
- the practicability of the various controls
- the efficacy of the different controls
- the consequences of failure of controls
- the relative costs of providing, operating and maintaining controls
- the acceptability by the workforce (if the control measures are viewed as impractical they will not be used).

The following situations are examples of best choice for workplace control:

- replace cancer-causing chemicals rather than controlling them, unless they are essential to the workplace (e.g. potent drug treatments in a hospital)
- an expensive dust-control system would not be recommended for intermittent or infrequent exposures (e.g. a job undertaken for 3 hours every 6 months) where respiratory protection would suffice
- half-face respirators, which might technically provide good protection, would not be recommended for a worker permanently employed on an acid pickling line; control of the acid aerosol by suppression and ventilation would provide a more acceptable long-term solution

- a worker requiring access to the same acid pickling line for 5 minutes per day can be adequately protected by the appropriate half-face respirator.

The experienced H&S practitioner will find that there are always a number of possible control solutions. Some work better than others, some are less expensive, some are more acceptable, others less so. The following sections discuss important details in selecting each kind of control.

4.3.3 KEEP CONTROLS SIMPLE AND INVOLVE OTHERS

Elimination and substitution is simple and effective and should always be considered first. Engineering solutions and ventilation usually incur some costs to gain effective control unless they are implemented at the design stage, in which case they rarely add significant cost. But administrative controls and personal protection rely heavily on the human responses. Both administrative controls and personal protection incur considerable complexities in the decision-making. Each relies heavily on worker compliance, worker acceptability, and the uncertainties and unpredictability of worker attitudes and behaviour. Decision-making on respiratory protection in particular requires greater information on exposures, equipment performance, worker training, and maintenance. Furthermore, failure of respiratory protection when it is used as the primary control mechanism provides no scope for a back-up. During each step of the development of the controls, all of the stakeholders (e.g. process managers, exposed work group, engineers) should be involved to ensure ownership of the solutions.

Wherever possible, the H&S practitioner should become involved in the design of new workplaces or processes. In this way best practices in design can be applied to eliminate hazards or at least minimise them. Retrofitting (engineering) controls is both expensive and generally less effective.

4.3.4 CHANGE MANAGEMENT

Often materials and processes find their way into the workplace without any effort being made to investigate their hazards or the alternatives. There are many cases where materials are introduced, usually in an effort to make the task easier, without sufficient thought being given to a new, introduced hazard. For example:

- new solvents to clean residues from parts may be toxic
- compressed air to blow components clean may generate a dust hazard
- UV lamps to cure resins may cause exposure to UV radiation.

A change management system should be in place to conduct risk assessments each time a new chemical or process is introduced or an existing one is changed. Change management controls are required by most OH&S regulations and should involve representatives from all affected workgroups.

4.4 ELIMINATION/SUBSTITUTION

Elimination of a hazard in the workplace, by removing a process or a substance completely, is the definitive way of reducing risk. In practical terms, however, the drastic step of eliminating a process central to a workplace may result in the closing down of an industry (e.g. airships which used hydrogen, or domestic fireworks manufacturing). Elimination is often rejected in favour of more practicable control alternatives.

Substitution offers a number of ways of controlling health hazards in the workplace. It can involve substitution of materials and/or processes.

4.4.1 MATERIALS

For some workplaces, it may not be possible to substitute the hazard—for example, in mining ores, or smelting metals. But substitution of one hazardous substance with a less hazardous one has been widely employed throughout history in many process industries. Radium painting of luminescent watch and clock dials was replaced with phosphorescent zinc sulphides after it was established that the radioactivity in the original paint caused bone and tissue cancer in the painters (particularly in those who licked the paintbrush to form a fine tip). White and yellow phosphorus matches, responsible for 'phossy jaw', a disfiguring and potentially fatal necrosis of the jawbone in match workers, were replaced by less dangerous red phosphorus matches. Modern safety matches incorporate an even safer tetraphosphorus trisulphide in the striking friction part of the box.

In fact, many of the developments in occupational health over the last 60 to 70 years have occurred specifically in the search for less hazardous substitutes. Other well-known examples include:

- replacement of cancer- and mesothelioma-causing asbestos fibres by safer synthetic substitutes (glass foam, rock and glass wool)
- removal of benzene (which causes leukaemia) as an industrial solvent and replacement by less hazardous aromatic solvents (e.g. xylene)
- replacement of beach and river sands, which have high quartz contents, as abrasive blasting agents, with low quartz content materials (ilmenite, zircon, copper slag)
- replacement of mercury compounds for fur carroting by less hazardous organic acid peroxide mixtures
- replacement of petroleum naphtha with carbon tetrachloride for dry-cleaning; carbon tetrachloride was successively replaced by perchlorethylene and then chlorofluorocarbons (with a subsequent return to perchlorethylene when CFCs became restricted as ozone-depleting substances)
- replacement of mercury retorting for gold extraction by cyaniding, and 'carbon-in-pulp' leaching.

These examples represent some classic advances. But in today's workplaces there are still many instances where substitution with less hazardous materials could occur.

Lead can be phased out of many workplaces, as can mercury and hexavalent chromium salts. Other far less toxic aliphatic hydrocarbon solvents can replace the aliphatic solvent n-hexane, which is still used in some printing solvents. Nonetheless, care must still be taken to ensure that the substitute does not introduce other unwanted hazards.

4.4.2 PROCESSES

In some industrial processes, where substitution to a less hazardous material is not possible, the risk in handling hazardous materials can be reduced by a change in the process. For example:

- use a pelletised form of masterbatch instead of a dusty powder (e.g. lead stabilisers in PVC pipe production)
- use a gelled form of organic solvent which reduces the rate of vapour emissions (e.g. gelled styrene, gelled paint strippers)
- choose a manufacturing route which does not give off hazardous by-products (e.g. the unwanted by-product of dioxin in herbicide manufacture)
- choose a manufacturing route which does not require storage of large quantities of extremely hazardous intermediates (e.g. methylisocyanate in pesticide manufacture, or hydrogen cyanide in manufacture of potassium cyanide)
- change from a dry to wet process for dust control (damp sawdust), or from sweeping to vacuum cleaning (see Figure 4.1)
- lower the temperature to reduce evaporation of volatile materials.

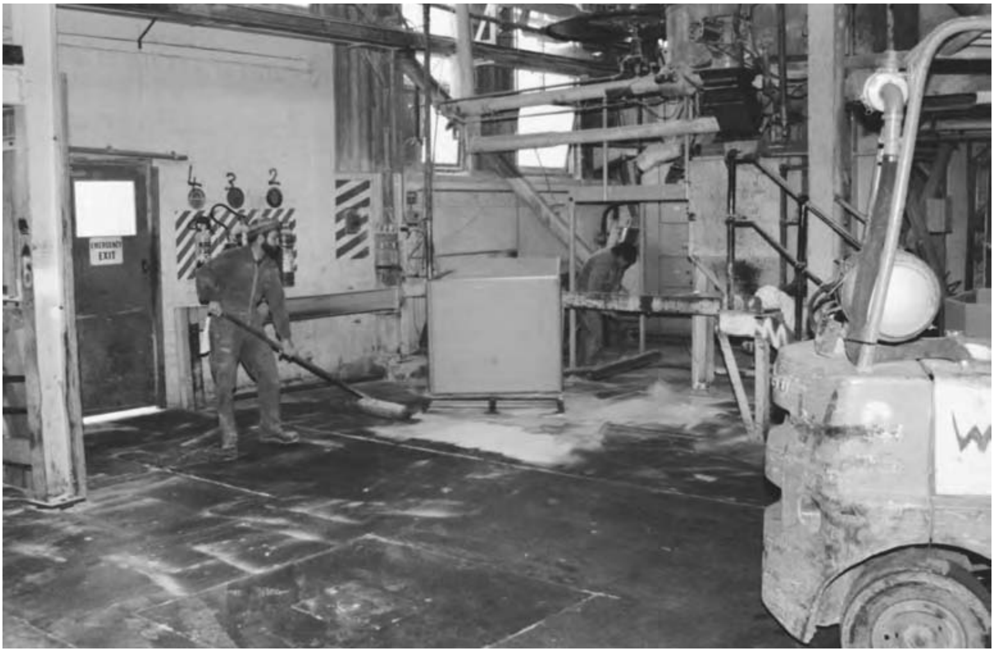


Figure 4.1 Dry sweeping generates dust exposure

In simple processes such as painting, dipping instead of spraying will control the generation of vapours to a great degree, while eliminating spillage and using low-dust cleaning methods, such as vacuuming rather than the dry sweeping shown in Figure 4.1, will reduce airborne dust.

If the workplace incorporates extensive processing of materials, it is wise to examine all potential ways of minimising hazards to health. For example, a task may have been done in a traditional way for years without any questions arising about its efficiency or safety. In some cases it will be possible to substitute a ready-made product from a purpose-designed workshop, rather than operate a hazardous process. The aim should be to:

- reduce the number of times a worker handles a hazardous material (e.g. the lead in manufacture of a battery may be handled in 20 or more separate operations)
- minimise operations producing hazards, particularly airborne hazards (e.g. restrict multiple dispensing of powders from storage to hopper to bin to bag
- use shrouded high-pressure water-blasting equipment when cleaning to reduce the spread of contamination)
- change process to reduce fugitive dust or vapour hazards (e.g. conduct cold acid pickling processes rather than hot to reduce evaporation of hazardous substances; use of floating ping-pong balls on the pickle liquor reduces airborne droplets; use liquid catalysis of chemical reactions, such as in foundry moulding, rather than gaseous catalysis).

The challenge to the H&S practitioner is to be alert to the possibility of substitution in order to reduce hazards. If the hazardous materials cannot be substituted because they are integral to a process or the processing cannot be improved, then one of the following control strategies should be implemented.

4.5 ENGINEERING-OUT THE HAZARD

A range of engineering controls is possible, including various types of containment and ventilation systems.

4.5.1 ISOLATION

When use of hazardous materials is unavoidable, the next best procedure often is to engineer-out the hazard by isolation. If the worker can be isolated completely from the hazard, the risk to health is removed. Isolation may be a physical or a distance barrier. Time is also a barrier, although time may equally be considered an administrative control.

The following examples illustrate the principle:

- the use of interlocked doors or barriers to prevent entry into an area while toxic substances are present
- remote storage of hazardous materials (e.g. explosives, fuel tank farms)

- separating materials that could create hazards by coming into contact with each other by accident (e.g. oxidants and fuels).

Occasionally it is possible to use timed sequences to conduct hazardous operations when fewer workers are present. For example, burning-off procedures might be restricted to evening hours, allowing several hours for a workplace to clear prior to re-entry. Painting of a workplace obviously should be conducted outside normal workplace hours to prevent unnecessary exposure to solvent vapours. Work on air-conditioning plants that may involve their shut-down should be restricted to periods outside normal working hours, particularly when duct-cleaning is required. Fumigating restaurants with pesticides cannot be conducted when staff or patrons are on the premises.

4.5.2 CONTAINMENT

Once an agent (dust, fume, vapours, noise) has escaped from the source it becomes far more difficult to control. A better strategy is to maximise the containment by engineering controls. For example:

- a whole process is totally enclosed and coupled with an exhaust extraction system
- sound-proof control rooms in noisy environments
- a glove-box or biological safety cabinet for handling infectious agents
- a remotely controlled laboratory to handle radioactive isotopes
- enclosing noisy machinery in sound-proofed structures
- gas-tight systems, used in chemical processing or in many sterilising or fumigation procedures.

The installation of totally enclosed or contained systems, also called containment systems, often has a high initial cost and can have the added problem of worker–hazard contact if the isolation system fails. The complete enclosure of a hazard is usually restricted to the extreme cases where escape of the hazardous substance could have serious health consequences or may be immediately life-threatening. Containment is normally supplemented with a ventilation system to ensure complete containment. Figure 4.2 is an example of an enclosed process, where a plexiglass enclosure is built around a corona discharge unit to contain the generated ozone. A small exhaust ventilation fan supplements the containment. In Section 4.8 on ventilation there are examples of the use of partial enclosures, a common and widespread method for control.

While a totally enclosed process is in operation there will be controls on operator exposure. However, on occasions of process upset or maintenance it may be necessary for staff to enter the enclosure. This event must be treated with extreme care and utmost caution. For example, entering a toxic pesticide melting oven for maintenance or entering into a fumigation process may require the operator to use high-integrity personal protective equipment, according to the specific risk.

Siting of such totally enclosed hazardous processes is important. They should not be sited in locations that could cause harm to the users or to bystanders if the enclosure system fails. Moreover, they should preferably be interlocked so the process cannot be operated unless the isolation system is operating. Furthermore, primary enclosed systems should be alarmed and have secondary back-up controls. Planning for the siting and operation of totally enclosed systems is crucial to their continued safety. An extreme example of an incorrect location is an ethylene oxide fumigation chamber, including cylinders of fumigant, in the centre of a library. An example of a good location is a hospital sterilising department that has its cylinders external to the normal workspace, is alarmed for leakage and is fitted with a continuous exhaust system to handle any accidental discharge of sterilant gas.

In any plant, the H&S practitioner should be aware of siting of all potentially hazardous operations and ensure that they are not in locations where control becomes difficult if there is a breakdown in the isolation system. For example, workers should not be able to stray into situations where without warning they could be at unnecessary risk. If new processes are being installed, particularly enclosed processes, they should not be sited in areas of constant or high worker access, and they must not impede exit routes in the case of emergency.

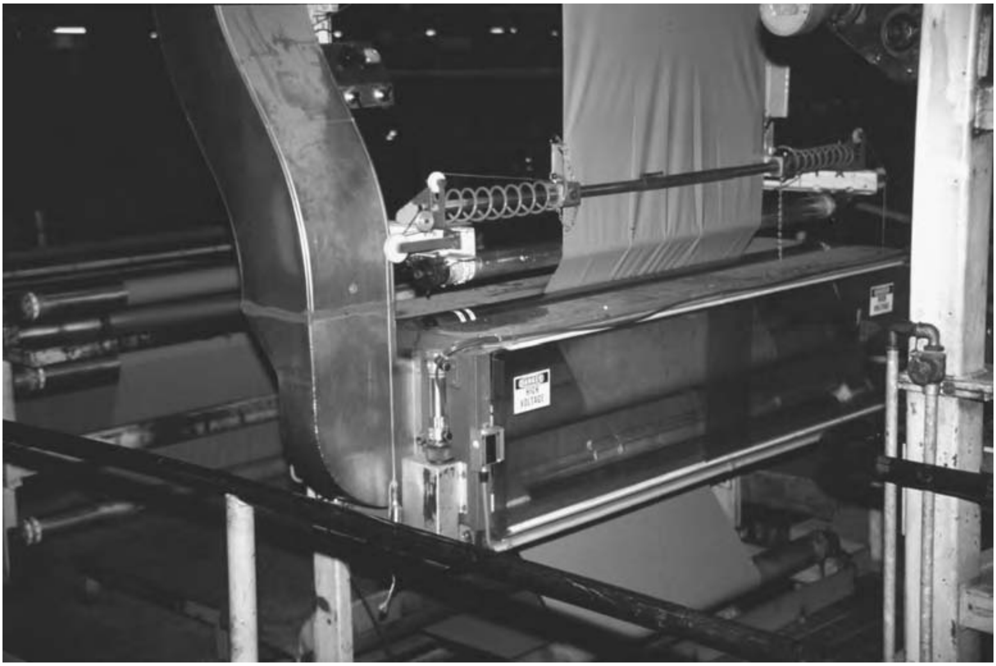


Figure 4.2 An example of a totally enclosed process: an ozone generating corona discharge supplemented with an extraction fan

4.5.3 VENTILATION

Industrial ventilation—the engineering control of contaminants by dilution or local exhaust ventilation—is one of the main methods of control of airborne chemical hazards and is covered in more detail in Section 4.8.

4.6 ADMINISTRATIVE CONTROLS

So far we have examined workplace exposure controls by eliminating the material or hazard, or by applying engineering control methods. These alone are frequently insufficient, so that it becomes necessary to change the system of work to achieve the desired level of exposure control. Changes to work methods or systems have traditionally been considered administrative controls. It would be simplistic to think that a single control strategy (except complete elimination) would result in satisfactory control of exposure. Sometimes higher level control mechanisms just do not work, or they cannot be made to work well enough to completely eliminate the hazard. For example, consider the following workplace situations:

- working inside a deep freezer
- working inside a hot oven
- working underwater at a depth of 100 m.

In the freezer and the oven, it is rarely practicable to introduce a microenvironment to compensate for the existing thermal environment. Efforts to keep divers at great depths for long times have to be very elaborate.

The use of administrative controls in regulating workplace hazards is an alternative strategy that concentrates on the work processes and systems, and worker behaviours, rather than the workplace hardware. While preference has to be given to engineering solutions, invariably special attention must be given to worker education, behaviour or work practices because conventional methods are neither feasible nor adequate to control the hazard. Administrative controls should not be confused with the usual management concepts such as responsibility, audit and review.

A full appreciation of the hazards of a particular workplace is often only achieved if a complete risk assessment is undertaken with involvement of all parties concerned. Most legislative jurisdictions require formal chemical risk assessments. The respective regulations relating to workplace hazardous substances call for the hazards to be identified, mainly based on the hazardous substances Risk Phrases used in material safety data sheets; for exposure routes to be defined; for the extent of exposure to be assessed; for exposure controls to be developed while applying the hierarchy of controls; and for all affected staff to be trained in all aspects of the hazard and its controls. These formal risk assessments are an integral aspect of the application of an *administrative* control in the workplace.

Work procedures such as teamwork can be an effective administrative control process for some dangerous tasks. For example, work in confined spaces is controlled by performing risk assessments and using work permits as described in AS/NZS 2865 (Standards Australia 2001b). The hazards of restricted visibility areas can be reduced by working in pairs or groups. Housekeeping and labelling are two administrative control processes that operate to limit inadvertent (especially skin) exposure to workplace hazards.

The importance of maintaining high standards of housekeeping cannot be over-stated. Dirty and untidy workplaces not only increase the likelihood of secondary exposures (e.g. dust raised by draughts and wind, or inadvertent skin contact on dirty surfaces and equipment) but may also send a message to personnel that poor work habits are acceptable.

To be able to use administrative controls properly, workers have to be adequately trained so they know:

- why the administrative control is being used
- the exact procedures and guidelines to be followed
- the limitations of such administrative control procedures
- the consequences of ignoring the administrative control.

In other words, worker involvement, participation, training and education are critical to the success of administrative control programs.

4.6.1 STATUTORY REQUIREMENTS

All health and safety laws and regulations, codes of practice and industry standards are effectively forms of administrative control. The way in which administrative controls are put into effect will depend on the particular workplace. Company health and safety policy and health and safety procedures, government regulations, and some industrial relations arrangements all have a place.

4.6.2 EDUCATION AND TRAINING

In many Australian OH&S Acts and Regulations there are requirements for training workers and others involved in health and safety activities. Where administrative controls are instituted (such as may occur under Hazardous Substances Regulations), the law generally requires training and induction of workers. Provision of information, such as the mandatory availability of a material safety data sheet, is an administrative control mechanism. Information systems are powerful administrative control mechanisms that operate unobtrusively in most workplaces and are often taken for granted.

Training programs should be formalised and administered long past the induction period and throughout the length of employment. Training should always incorporate the practical aspects of a job and include some form of competency assessment. If potentially exposed workers are made fully aware of not only the consequences of over-exposure but also the routes and mechanisms of exposure, they are more likely to identify other exposure situations and act to reduce exposures in new situations. In this regard it is useful in a training setting to use methods of exposure visualisation to demonstrate concepts. For example, fluorescein dye (a dye used by plumbers to trace drains) can be added to aqueous solutions to simulate toxic liquids. In order to show the degree of containment or the spread of contamination the traces of fluorescein can be made visible by using a UV lamp. Smoke generators can be used to test ventilation systems and can show the potential movement of contaminants within the workplace. Intense lighting can also be used to show dust generation, as seen in Figure 4.3.

Figure 4.3
Intense light illumination being used to highlight secondary dust off work clothes as a source of exposure (reproduced with permission, UK HSE)

4.6.3 WORK SCHEDULES AND WORK PRACTICES

Where work shifts and work schedules are varied from the normal 8-hour day/40-hour week, consideration needs to be given to changing the workplace exposure standards that are applied. See Chapter 3, The Concept of the Exposure Standard, for a full discussion of variations and theories.

4.6.4 WORKER ROTATION AND REMOVAL FROM EXPOSURE

An extreme form of work schedule change would be to rotate tasks within the workgroup to spread the exposure across a larger number of staff. In order for this to be a viable strategy the H&S practitioner must have a reliable system to measure the exposures of all in the workgroup.

In many circumstances, exposure to hazardous substances or a hazardous environment cannot be avoided. If any workers are exposed to the maximum permissible level then they may have to be removed from that task. Some examples are:

- in the lead industry, workers may be removed if blood lead levels exceed a certain level, and remain removed from further lead exposure until blood lead levels fall to an acceptable level
- in some European countries, coal mining workers are permitted a maximum cumulative exposure, e.g. 72 mg/m^3 years (i.e. 12 mg/m^3 for 6 years), and then removed to a totally non-dusty environment

- workers in ionising radiation industries are permitted a maximum radiation dose over a specified time period
- workers in excessively noisy industries, who cannot be adequately protected by hearing protection, should have noise exposure reduced by reassignment so that their daily equivalent noise exposure does not exceed 85 dB(A) Leq.

Where workers have developed sensitivity to a substance, one common administrative control is to prevent any further exposure. In other instances workers may be predisposed to effects at lower thresholds than the average worker, or they may be diagnosed as showing effects due to exposure without actually being symptomatic. Examples are:

- isocyanate-sensitised workers are prevented from any further exposure
- workers with radiologically-confirmed dust disease may be precluded from further work in dusty underground mining
- workers with certain genetic dysfunction should not be occupationally exposed to TNT or chemicals causing haemolytic anaemia
- pregnant workers should not be exposed to known foetal toxins (e.g. lead, ethylene glycol ethers)
- asthmatics should not work with strong irritant gases.

There are examples from history where worker blood lead levels were controlled by compulsory withdrawal from exposure rather than by controlling the actual routes of exposure. This method of exposure control is suggestive of failure of all other controls, and the H&S practitioner would be advised to re-evaluate all aspects of the control systems and strategies.

4.7 PERSONAL PROTECTIVE EQUIPMENT

At the start of this chapter, the hierarchy of controls was discussed. At the bottom of the hierarchy is personal protective equipment (PPE). PPE represents the absolute last resort; beyond the PPE is the unprotected worker and inevitable exposure if the PPE is not correctly selected, maintained and used. Even though PPE is on the bottom of the hierarchy it is still widely used and accepted as a back-up and supplement for other controls. There will also be situations where higher level controls cannot be used and PPE will be the only practicable solution.

4.7.1 SAFETY EQUIPMENT

Basic safety equipment is fundamental to protecting the human body from physical hazards at work; it includes hard hats, safety boots, overalls, safety glasses or goggles, hearing protection and gloves for protection from cuts and abrasions. For the most part, immediate protection of the eyes, hands, head and feet is relatively uncomplicated. The hazards are usually obvious and programs to use personal protective equipment can be implemented with relative ease. The protective device is designed to isolate the worker from the hazard. It does not remove the hazard from the workplace, but reduces the risk of injury if the worker accidentally comes into contact with the hazard. Matters relating to these safety concepts will not be extensively described in this book. In some instances excessive use of PPE can compromise the worker's ability to accurately perceive the work environment and may compromise personal safety.

For example, overprotection through the use of hearing protection with high attenuation may disguise alarms and other warning noises. In some instances the workers may complain of being treated as a 'Christmas tree', with pieces of PPE hung on them like decorations, as seen in Figure 4.4. Considerable care should be taken when choosing basic PPE to provide the correct level of protection. Overuse of PPE is likely to result in the PPE not being used at all, leaving the worker totally unprotected. A thorough understanding of the hazard is essential to ensure the appropriate PPE is chosen. For example, the worker shown in Figure 4.5 is using heated methylene diisocyanate (MDI), a powerful skin and respiratory sensitiser. In this case there is no protection from vapours and the single glove of inappropriate material provides no resistance to the chemical. Bare skin is also exposed.

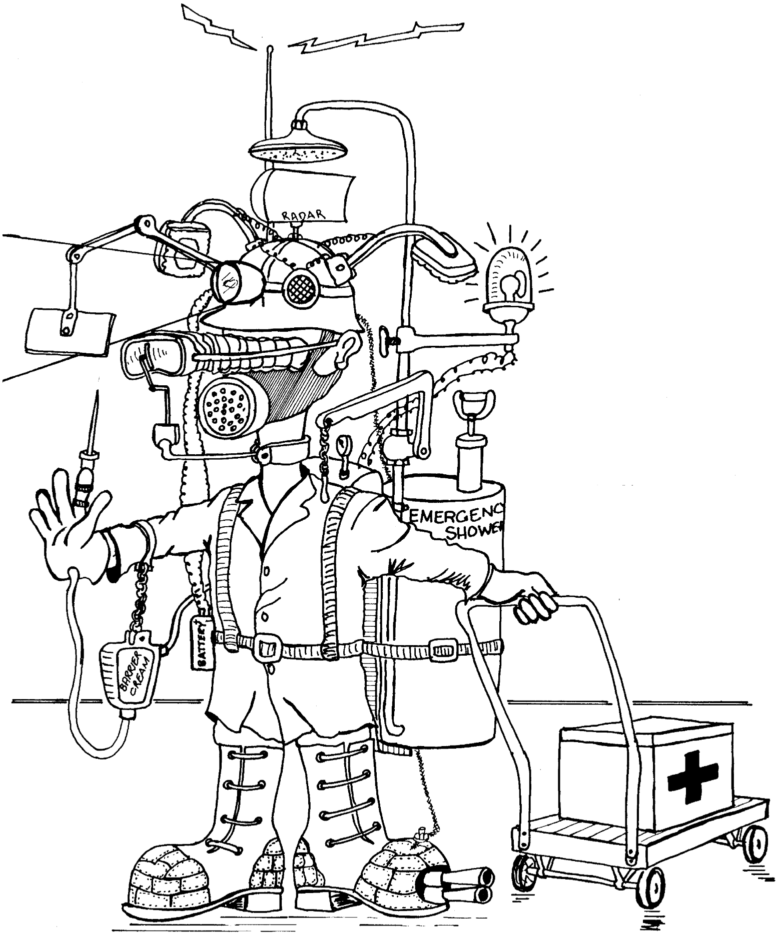


Figure 4.4 An example of overuse of PPE

Figure 4.5
Inappropriate PPE for methylene diisocyanate, no eye protection, no vapour emission controls, only one (inappropriate) glove and bare skin exposed

4.7.2 GLOVES

Most people use their hands all the time at work and consequently hand injuries are very common. These injuries can be physical trauma or chemically-induced damage, as shown in Figure 4.6. Consequently gloves are widely used in industry for hand protection against many different materials. The selection of the correct glove type is neither straightforward nor simple. For example, gloves that protect against methylated spirit solvents may not protect against turpentine. Knowledge of the chemical and permeation resistance of different glove materials is required before making a choice. All the major glove manufacturers publish data on the resistance of their glove material to permeation by the common solvents used in industry. However, the permeation resistance data from one manufacturer may not hold true for that same type of glove material from another manufacturer. Other aspects to consider when choosing gloves include the dexterity required of the worker, thermal resistance, abrasion and puncture resistance. The favoured leather 'rigger's' glove offers virtually no chemical resistance and can act as a reservoir of chemical to slowly penetrate through the glove and then to the user.

The re-use and laundering of gloves can be fraught with problems and any decision to do this should be approached with caution. Some of the problems include:

- gloves may have small holes that are not detected
- contaminants can be moved to the inside of the glove during washing

- the washing process can physically damage the glove
- the washing process may not remove any chemical that has started to migrate through the glove material.

A successful skin protection program includes correct glove selection as well as training in their correct use, in the limitations to their protection, and their correct removal without causing contamination of the skin.

Skin lotions and hand cleaners may contain petroleum products that can cause swelling and degradation of the glove material. Specialist advice should be sought from the glove supplier if there are any concerns (Figure 4.6). Users of the gloves need to be alert and if any deterioration is noticed the gloves should be removed and their suitability reassessed.

Figure 4.6 An example of severe contact dermatitis caused by chemical contact with skin

Most users need to be shown how to remove gloves correctly without causing contamination of the unprotected skin. Loose-fitting gloves can be shaken off quite easily. Tight-fitting gloves should be removed by grasping the cuff of one glove and pulling it down and inside out. While the partly removed glove is still on the hand, the second glove is pulled down and inside-out without touching the bare skin with any contaminated glove surfaces. The gloves are finally removed with one partly inside the other. It is not recommended that these types of gloves be re-used, because of the risk of introducing contamination onto their internal surfaces. If this were to occur, the enclosed nature of the glove material may increase the rate of the absorption of the agent the gloves were intended to protect against.

4.7.3 RESPIRATORY PROTECTIVE EQUIPMENT

There are many applications where the use of respiratory protective equipment (RPE) is an established method of protection for reasons such as:

- other control methods are far too costly or impracticable (e.g. electrical power may not be available, or ventilation controls cannot be arranged around a large open formwork metal structure)
- the task may be carried out at various locations (e.g. a pesticide applicator providing termite treatments to buildings)
- the task may involve only short-term exposures (e.g. one job lasting 2 hours per month)
- exposure may be only trivial, not requiring elaborate controls (e.g. nuisance dust exposure)
- use of materials which have very poor or no warning properties and overexposure can readily occur
- RPE is required for emergency procedures, including emergency escapes (e.g. fire fighting, escape from chemical leaks or spills)
- air-supplied RPE is mandatory for entry into oxygen-deficient or partially oxygen-deficient atmospheres
- RPE is necessary to supplement other control procedures
- air-supplied RPE is still required for abrasive blasting even when water suppression is used.

RPE cannot be used arbitrarily. It also should not be used just to quell complaints by workers of overexposure to contaminants. Prior to issue of any RPE, full investigation of the work with hazardous substances should occur to ensure that use of RPE is an appropriate control measure.

RPE offers a means for relatively simple, low-cost protection from hazards that arise in many workplaces. However, it must be stressed that effective use of RPE programs is often difficult (and sometimes impossible) to achieve. Any H&S practitioner embarking upon an RPE program needs to be aware that this protective strategy requires 100 per cent commitment from both management and the worker. If there is any lack of enforcement on the part of management or lack of compliance on the part of the worker then the protective measure will fail. RPE use requires much greater organisational effort than for other kinds of hazard control. If RPE is adopted, this should only be after examining all other options for protecting the worker.

4.7.3.1 Regulatory requirements

Any RPE program should be in keeping with the requirements of:

- any advisory standard or code of practice on personal protective equipment
- AS/NZS 1715 *Selection, Use and Maintenance of Respiratory Protective Devices* (Standards Australia 1994)
- AS/NZS 1716 *Respiratory Protective Devices* (Standards Australia 2003).

The Hazardous Substance Regulations mention the use of personal protective equipment, which includes respiratory protection, but only as a last resort in control of hazardous substances and with no operational detail.

4.7.3.2 Respiratory protection programs

The implementation of a respiratory protection program needs to be based on a detailed assessment of each workplace hazard, including exposures. For example, if the workplace uses lead, and other controls are not possible, it will be necessary to determine which type of RPE will be appropriate for lead dust. The wrong choice of RPE could result in excessive lead risk to workers, with possible regulatory actions or fines, or civil action by employees, or it may result in unnecessary economic costs to the business if an elaborate protective regime is selected. Therefore the procedures for selecting and implementing RPE require considerable attention. Where doubt exists the specific needs should be discussed with representatives from the RPE supply company.

There are some excellent respiratory protection programs operating throughout Australia. However, many purchasers of respiratory protection fail to get satisfactory performance from their RPE for reasons which include:

- a lack of knowledge about the nature of the airborne contaminant and its concentration levels
- incorrect selection of air-purifying devices
- incorrect selection of class of RPE (i.e. efficiency and protection factors)
- poor fitting of respirators
- no scheduled maintenance
- ill-treatment and contamination of RPE in the workplace
- lack of knowledge on filter life
- workers failing to use the RPE provided at the appropriate time.

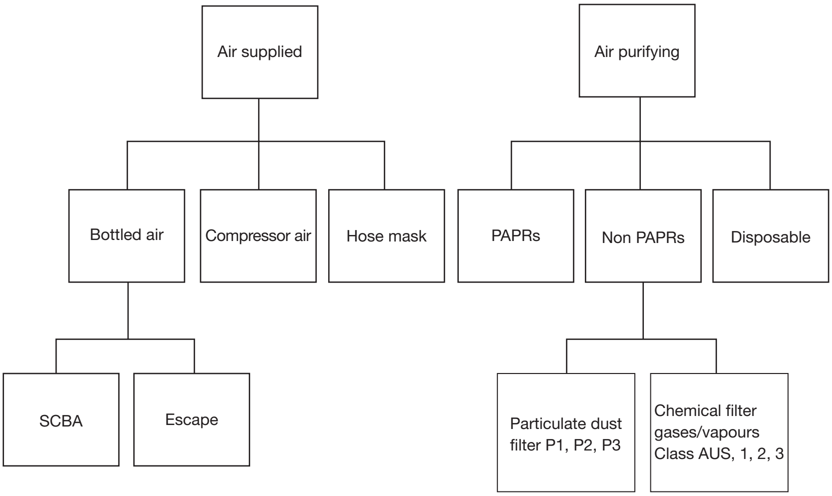


Figure 4.7 Classification of respiratory protective equipment

Table 4.1 Main types of respirators encountered

Respirator type	Function or purpose
Particulate filter classes	
P1	Protection against mechanically generated particulates Filter penetration <20% (face seal may limit performance)
P2	Protection against mechanically and thermally generated particulates Filter penetration <6%
P3	Protection against all particulates including highly toxic materials Filter penetration <0.05%
It should be noted that 'handyman' dust masks that do not carry the Australian Standards® mark do not provide protection against toxic or hazardous dusts. Extreme caution should be exercised when selecting this type of respiratory protection.	
Air purifying, powered type	Powered air purifying respirator (PAPR) uses a battery-driven fan to force air through a filter assembly and deliver cleaned air to a helmet, hood or face mask.
Air purifying, replaceable filter type	A facepiece (full face or half face) to which a replaceable filter assembly is connected. The user's lung power is used to draw the air through the filter.
Air purifying, disposable	A respirator with the filter as an integral part of the facepiece and the filter is not replaceable. When exhausted the whole assembly is discarded.
Supplied air, air hose	The respirator facepiece is connected by a wide diameter hose that is located outside the contaminated zone. The user's lung power draws air to the facepiece (can be low pressure fan assisted). The critical factor in air hose systems is they supply air at or near atmospheric pressure.
Supplied air, compressed air-line	Air for respiration is supplied by a small bore line that is connected to a compressed air source. This may be a compressor, or compressed air cylinders located a distance from the work location. There are specifications in AS 1716 regarding the purity of air supplied systems and SCBA systems.
Supplied air, self-contained	The respirator facepiece is connected by a breathing tube to a cylinder of breathable gas that is carried by the wearer. Often referred to as SCBA.

Gas/vapour filter classes	
Class AUS	Low absorption capacity filters
Class 1	Low to medium absorption capacity filters
Class 2	Medium absorption capacity filters
Class 3	High absorption capacity filters
Gas/vapour filter types	
Type A	For use against certain organic gases and vapours as specified
Type B	For use against certain inorganic gases and vapours as specified, excluding carbon monoxide
Type E	For use against sulphur dioxide and other acid gases and vapours as specified
Type G	For use against certain organic compounds with vapour pressures less than 1.3 Pa (0.01 mm Hg) at 25°C as specified. These filters shall have an integral particulate filter with an efficiency at least equivalent to that of a P1 filter.
Type K	For use against ammonia and organic ammonia derivatives as specified by the manufacturer
Type AX	For use against low boiling point organic compounds as specified by the manufacturer (boiling point less than 65°C)
Type NO	For use against oxides of nitrogen
Type Hg	For use against metallic mercury
Type MB	For use against methyl bromide

Source: AS/NZS 1716 (Standards Australia 2003)

If all the strategies of substitution, engineering-out the hazard, ventilation, etc., are impractical or unavailable, and respiratory protection is chosen as the principal control method, there is no further fallback position.

There are many different types of respirators and it is not the intention of this text to provide a detailed evaluation of each type. As a guide the types of respirators are summarised in Figure 4.7 and described in Table 4.1. For more detail consult AS/NZS 1716 (Standards Australia 2003).

Great attention to the technical detail and administration of RPE programs is necessary. There are many anecdotes and examples related to the incorrect use of respirators, like the dusty respirator hanging on a nail in a workshop, fitted with a dust filter used during spray painting with a paint containing solvents and lead, used by a bearded operator who could not recall when the filter was last changed. However, the sales person who sold it to him assured the operator it was the correct one for spray-painting lead paint.

The key requirements of an RPE program include:

- managerial capacity to administer an RPE program (it is part of the H&S practitioner's task to guide the managers)
- knowledge of respiratory hazards
- workplace assessment of the respiratory hazards
- selection and purchase of appropriate type of RPE and protection factor
- acceptance of RPE by workers
- medical assessment of respirator use for some RPE users
- training in use, including correct fit of respirator
- inspection, maintenance and repair of RPE
- audit and review.

The person selecting and supervising the RPE program will also require training. Written guidelines should be adopted and strictly adhered to. Use of RPE must be strictly monitored to ensure it is not used for purposes beyond those designated. When RPE is available in a workplace, it is possible workers may extend its use into a life-threatening situation if inadequately instructed.

4.7.3.3 Knowledge of respiratory hazards

It is not possible to proceed with an RPE program unless there is a clear understanding of why RPE is being used. Using any sort of RPE simply to stop workers complaining might not be in the workers' or the employer's best interests. Further, an inspector from a regulatory authority would not normally request use of RPE without some knowledge of its efficacy or acceptability, nor would an inspector usually be able to recommend the kind of RPE suitable to all workplace applications.

Many factors need to be considered. If choosing local exhaust ventilation (LEV), for instance, as a preferred control, it may not be necessary to know anything much about the nature of the hazard, its concentration in the workplace, which of the workers are at risk, or how far the contaminant spreads. LEV will simply exhaust the contaminant away and remove the problem.

In contrast, to provide proper respiratory protection, the following steps must be taken:

1. Determine whether the workplace situation is immediately dangerous to life or health (IDLH), and the potential consequences of failure of the RPE.
2. Determine the identity of the hazardous contaminants to be controlled (i.e. dust, mist, fume, gas, vapour, asphyxiant or any mixture of these).
3. Define the areas where the RPE is to be used (e.g. primary hazard areas).
4. Determine which workers require RPE. All workers in a particular process may not be at risk.
5. Distinguish whether RPE is the major control method or a back-up or secondary control.
6. Determine whether there are any additional routes of entry other than inhalation, or other effects. Skin absorption and effects on the eyes are the most common considerations.

4.7.3.4 Protection factors

Selection of correct RPE should not be attempted by the inexperienced and the untrained. Some regulations or codes of practice (e.g. ASCC *Asbestos: Code of Practice and Guidance Notes*) spell out the minimum RPE for situations where it is required. AS/NZS 1715 (Standards Australia 1994) should be consulted to select the most appropriate RPE. On occasions, trials of different types and brands will be necessary to determine the RPE that is most suited to a particular workplace. Suppliers of RPE are an excellent source of information and guidance.

There are two crucial pieces of numerical information needed in applying RPE successfully. They are:

- the concentration of contaminant in the workplace
- the target concentration inside the respirator.

Based on these data it is possible to calculate the required minimum protection factor expected from particular RPE.

The following formula should be used to determine the required minimum protection factor:

$$\text{Required minimum PF} = \text{concentration in workplace/WES (or other target)} \qquad \text{(Equation 4.1)}$$

Concentration and WES (workplace exposure standard) should be in the same units (not exclusively in ppm, can be mg/m^3).

The **required minimum protection factor** is a crucial piece of information when selecting RPE. It relates to the capacity of the respirator to reduce large concentrations of the contaminant *outside* the respirator to an acceptable (not necessarily insignificant) concentration *inside* the respirator. Some information on typical protection factors is given in Table 4.2. Comprehensive tables of the protection factors for various respiratory protective devices from suppliers should be consulted.

As an example, let us say the cyclohexane concentration in a workplace is measured as 1800 ppm. Cyclohexane can be removed with filtering type respirators with Class AUS, 1, 2 or 3 filters. The required protection factor to reduce the 1800 ppm concentration to below the WES target concentration of 100 ppm will be 1800/100 = 18. Table 4.2 indicates that only full facepiece respirators with Class 2 or 3 filters will have the required minimum protection factor to be used above 1000 ppm. (There are, however, other types available and suitable, as outlined in Table 6.3 of AS/NZS 1715 (Standards Australia 1994)—half-face, air-line, continuous flow, PAPR 2 in full-face, etc.)

AS/NZS 1715 also contains an excellent decision tree on arriving at suitable RPE for most applications. This Standard deals with respirator selection under the simplified headings of contaminant, task and operator.

4.7.3.5 Filter service life and breakthrough

When introducing air-purifying RPE to control exposure, attention must be directed to usage patterns and exposures in order to estimate the service life of protective filters.

Table 4.2 Required protection factors for selected respiratory devices

Required minimum protection factor	**Type of contaminant**	**Respirator type**
up to 10	Mechanically generated particulates, e.g. silica, asbestos	Disposable facepiece respirator, half-face respirator with P1, P2 or P3 filter
up to 50		PAPR with P2 filter, full facepiece with P2 filter
up to 100		Full facepiece with P3 filter
100 +		Full facepiece air-line respirator—positive pressure
up to 10	Thermally generated particulates, e.g. welding fume	Disposable facepiece respirator, half-face respirator with P2 or P3 filter
up to 50		PAPR with P2 filter, full facepiece with P2 filter
up to 100		Full facepiece with P3 filter
100 +		Full facepiece air-line respirator—positive pressure
up to 10	Gases and vapours, e.g. ammonia, xylene	Disposable facepiece (to 1000 ppm)
up to 10		Class AUS, 1, 2 or 3 replaceable half or full facepiece filter (to 1000 ppm)
up to 50		Full facepiece with Class AUS or 1 filter (to 1000 ppm)
up to 100		Full facepiece with Class 2 filter (to 5000 ppm)
up to 100		Full facepiece with Class 3 filter (to 10 000 ppm)
100 +		Full facepiece air-line respirator, SCBA—positive pressure demand

Source: data based on AS/NZS 1715 (Standards Australia 1994)

Service life is dependent on the filter construction and on workplace factors such as exposure conditions, the concentration of the contaminant, temperature and humidity, and the worker's breathing rate and general respiratory competence. Service life must include some unexpended reserve capacity as a safety margin. Importantly, filters should not be used beyond expiry of their shelf life.

A recurring question is: how long will the filter in the respirator last? To some extent, only experience will tell, so it is better to rely on outside experience or advice from manufacturers rather than chance unsafe practices.

For any type of respirator, wearer acceptance is also an important factor in adoption of RPE. For particulate filters, filtration efficiency usually increases with use as dust particles slowly block the filter. This causes increased inhalation resistance. This may have adverse effects for the wearer when RPE is used for continuous work or if the wearer has some medical respiratory condition that makes respirator use difficult. The service life of such filters is ended when the wearer can no longer tolerate the increased breathing resistance.

For gas and vapour filters, minimum service lifetimes can be calculated only if there is reliable data on exposure conditions. Otherwise, scheduled maintenance and replacement programs with a reasonable margin for safety must be scrupulously adhered to. Several RPE manufacturers have software for service life calculation.

Breakthrough of the contaminant, as indicated by odour, is a totally unreliable means of determining the end of service life (exhaustion of capacity) of a respirator filter. Some contaminants have no odour; others have workplace exposure standards well below their odour threshold. In some cases, such as hydrogen cyanide, breakthrough might have disastrous consequences, particularly since only half the population is genetically able to detect it by odour.

Figure 4.8 Qualitative facial fit testing using a saccharin aerosol

4.7.3.6 Training in use, fitting and testing

Tests for correct fitting of the RPE in use can only be conducted using the proper equipment. To test qualitatively for facial leaks, the wearer typically is subjected to an aerosol (Bitrex, saccharin) or isoamyl acetate vapour test, as illustrated in Figure 4.8. The respirator user has a hood over his head and an aerosol of saccharin is aspirated into the hood. The user is asked to perform a series of exercises involving talking and head movements. Any failure of the face seal will be detected by the taste of saccharin. This method is only suitable to test face seals on respirators fitted with particulate filters, as the particles can pass through gas and vapour filters. A similar test can be conducted where organic vapour air purifying respirators are used by using isoamyl acetate vapour as the challenge agent.

The more complex quantitative face-fit tests use a particle detector and a modified respirator facepiece to detect the inward leakage of an aerosol. Some tests of this type use ambient aerosols naturally occurring in the environment while others use a generated sodium chloride aerosol or oil mist. These tests require both specialist equipment and training.

Both types of tests (qualitative and quantitative) help ensure the selected respirator adequately fits the face of the wearer so that in future they will receive suitable protection. The tests should be performed at the time of issue and whenever respirator types are changed. Additionally, the tests reinforce with the respirator user the need to carefully put on the respirator each time, and can also demonstrate the effect of damaged parts or the effect of facial hair on impairing face seal. Any facial hair, particularly stubble beard growth, can interfere with the sealing of the respirator; all wearers should be clean shaven in the area of the face seal.

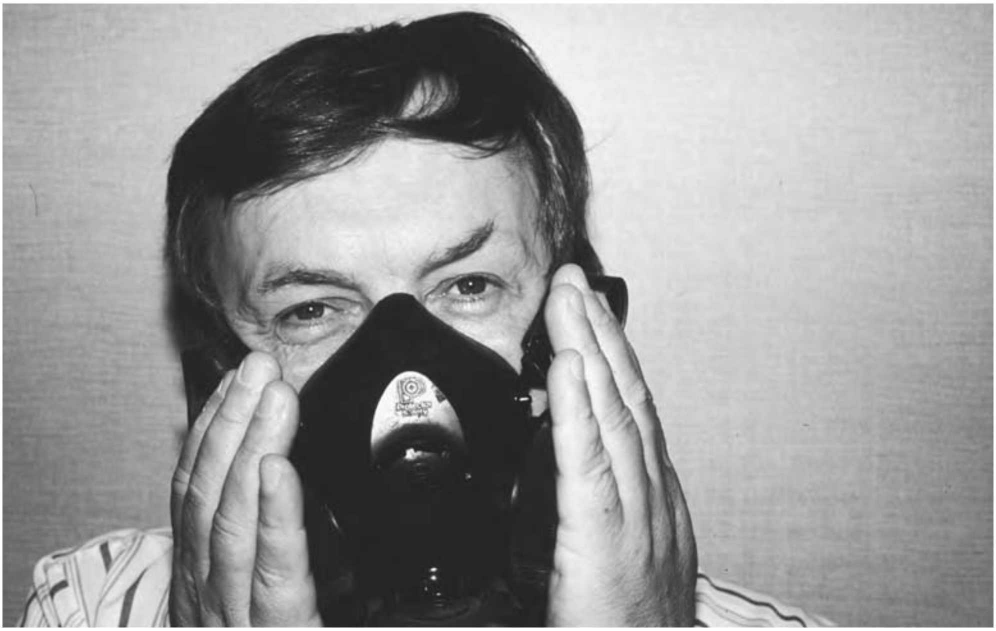


Figure 4.9 Negative pressure fit check

A gross negative pressure fit check can be done to check for leaks by blocking off the filters using the palms and inhaling (see Figure 4.9). Any inward leakage can be detected. This test is not very sensitive however, as the negative pressure within the respirator facepiece causes the respirator to be drawn onto the face by the external atmospheric pressure, improving the seal on the face. A similar positive pressure test can be done by exhaling while covering the filters or exhalation valve and trying to detect leakage. These checks are *not* substitutes for fit testing, but are used after donning respirators to ensure they have been put on correctly.

4.7.3.7 Inspection, maintenance and repair

With the exception of disposable filter type respirators, the use of RPE in the workplace requires a constant program of inspection, maintenance and repair. Maintenance includes washing, cleaning, disinfecting where necessary, inspection for wear, checking for leaks and replacement of worn components and replacement of filter components. It is essential to have proper storage in between use. Gas and vapour filters can continue to absorb contaminants when not in use, further exhausting their capacity. Plastic sealable food storage containers or zip-lock plastic bags are ideal for between-use storage. Suppliers of equipment will be able to provide details of suitable programs for their particular equipment. Where possible, each wearer should be provided with his or her individual RPE. Where air compressors are used for air-supplied respirators there should be a maintenance, inspection and testing program in place for the compressors as well, to ensure the air quality.

4.7.3.8 Medical assessment for suitability of RPE for some users

Wearing RPE is not without its physiological and psychological limitations. There are a number of medical conditions, including diabetes, asthma, emphysema, skin sensitivity, a punctured eardrum or chronic airways disease, that prevent a worker from using RPE. Some workers also feel claustrophobic wearing a normal filter respirator, but may find a powered air purifying respirator (PAPR) more acceptable. Always seek expert medical advice from a source experienced in respiratory medicine if prospective wearers have problems wearing respirators.

In some cases, biological testing (e.g. blood lead testing) may be added to ensure respirators continue to deliver the expected protection efficiency.

4.7.4 A FINAL WORD ON PPE

If personal protective equipment is used as a primary method of protection, then it is essential that robust systems are in place to provide reassurance that the level of protection continues to be achieved. Such systems may include workplace behavioural safety programs, in-house inspections and audits, routine training or ‘toolbox talks’ or biological monitoring (mentioned above).

The H&S practitioner should only resort to personal protective equipment when other means of exposure control are impracticable. Use of any protective equipment places restrictions upon workers; it reduces the flexibility of a worker’s operation and affects performance. If an H&S practitioner recommends that a worker should work permanently in PPE, he or she should try wearing the same protection themselves for 1 week to judge its suitability as a long-term measure.

4.8 VENTILATION

Industrial ventilation can be an effective way to control toxic exposures or provide greater comfort to workers, if it is well-designed and maintained. The health component should ensure that occupants are not exposed to air contaminants at harmful concentrations, while the comfort component requires that a substantial majority (at least 90 per cent) of occupants should not express dissatisfaction at the thermal environment or odour. However, note that expectations also influence dissatisfaction, as workers in hot or smelly industries will generally accept a large degree of discomfort without complaint.

4.8.1 CONCEPTS AND MYTHS

An understanding of some simple concepts is essential to the recognition of poorly designed industrial ventilation systems. Unfortunately, poor design, poor installation and poor maintenance are very common, all of which may be exacerbated by modifications to a ventilation system without understanding the impact on its performance.

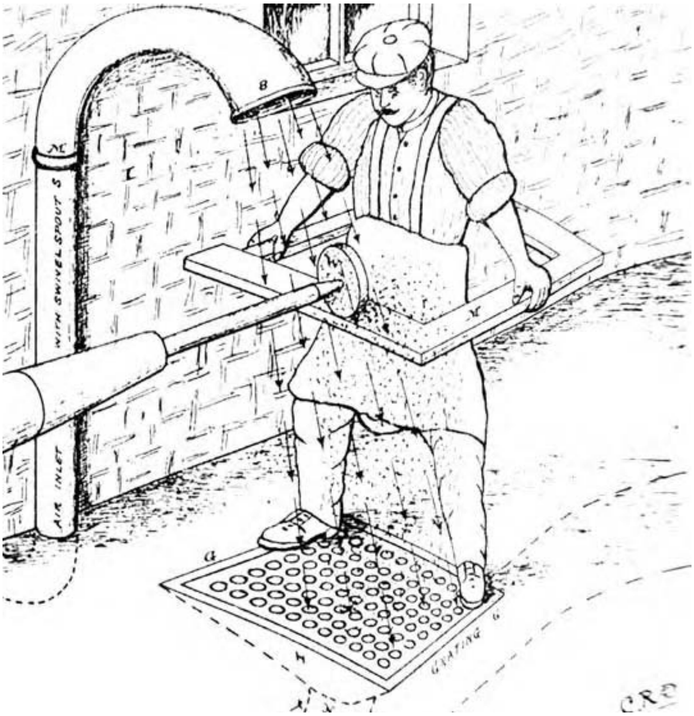


Figure 4.10 Contaminated air moving away from worker's face (HMSO 1907)

4.8.2 AIR MOVEMENT

If contaminated air is induced to move away from a person's face (Figure 4.10), then it is likely the person will be exposed to less of the contaminant. This may appear trite, but many industrial ventilation systems do the opposite of this through poor design or a lack of understanding of air movement.

In Figure 4.10, the worker is grinding a casting with a small wheel and has almost unrestricted movement. Clean air is supplied by a duct and the contaminated air is removed by an extraction system under the grate at his feet.

4.8.2.1 The barbecue effect

When you cook on a barbecue, you find that if you stand downwind the smoke blows into your face. This is expected. However, what is not expected is that when you move upwind, the smoke seems to follow you. What is happening is that the air swirls downwind of your body, trapping some smoke. This may be called the 'barbecue effect' and is shown in Figure 4.11.

In Figure 4.11 (left), smoke is released through a diffuser at X, downwind of a mannequin's head. A similar phenomenon occurs with a person's body (right), or with a fume cupboard or workbench as the air flows past the operator. Contaminated air in front of the operator's body swirls up to their face and they inhale some of it. On a larger scale air swirls around buildings, so that contaminants released downwind of a building, but in the building's wake, can be drawn back into the building.

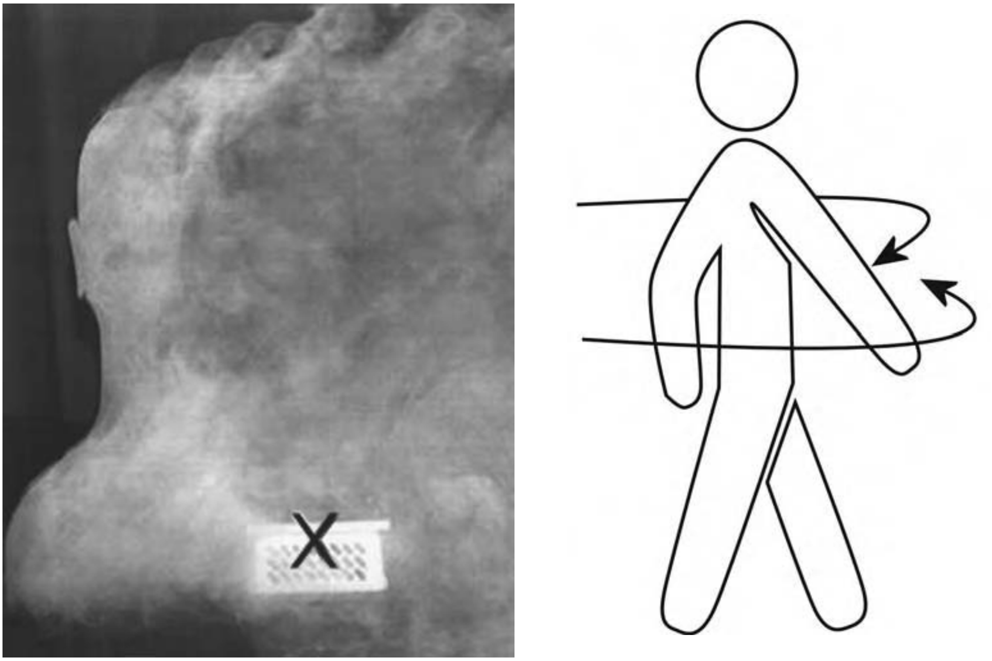


Figure 4.11 The barbecue effect

In many workshops a fume extraction system is placed above the worker to capture fumes from processes like welding. However, the extraction system produces a local flow of replacement air which swirls around the worker, so that instead of the contaminated air moving directly upwards, it tends to move towards the person's face. In this situation, the concentration of fumes inside a welding helmet can be higher than outside the helmet.

4.8.2.2 Sucking and blowing myth

An understanding of the difference between sucking and blowing air is fundamental to industrial ventilation design. The difference can easily be demonstrated.

Hold your hand a distance from your mouth and blow towards it. The air movement is easy to feel and a birthday candle can be blown out at arm's length. The flow is in a jet and very directional. However, when you breathe in or suck air through your lips, the airflow is from all directions and much of it moves over the surface of your face. If you try to suck out a candle (you may burn your nose if you attempt it!), the flame will be only millimetres from your lips before you can extinguish it. This fundamental difference between sucking and blowing can be used to explain why many industrial ventilation systems are ineffective, because the hood is placed too far from the source of contaminated air—and why the seal between the face and a respirator is so important when you inhale.

When a fan (or open duct) blows air, the velocity drops to 10 per cent of the maximum in about 30 to 60 fan (or duct) diameters. When air is sucked, this velocity drop occurs within one diameter of the fan or duct. This can be observed with a small fan such as a desk fan (Figure 4.12). The airflow can easily be felt at some distance in front of the fan, but only close to the back of the fan.

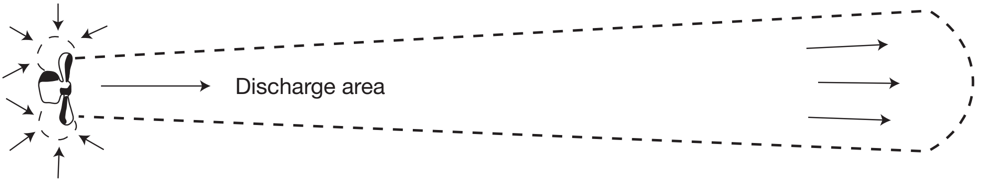


Figure 4.12 Sucking and blowing air (after HMSO 1907)

Industrial ventilation systems are often designed and installed by contractors familiar with air-conditioning systems that condition air and blow it into buildings. The fans, ducts and some of the air-cleaning systems are much the same as for industrial ventilation, but now the air is being sucked rather than blown, and that difference may not be understood. This often results in industrial ventilation systems that do not adequately protect the user from exposure to contaminated air.

4.8.2.3 The 'heavier than air' myth

It is not uncommon to find industrial ventilation systems in workplaces designed to remove 'heavier than air' vapours and gases from near the floor. It is true that vapours and gases can be found near floor level, but usually only at very high concentrations, often orders of magnitude above exposure limits (see Figure 4.13), where there are no temperature (isothermal) gradients or other air disturbances from moving people or machines. This may occur in the confined bilge of a boat, but this is an exception.

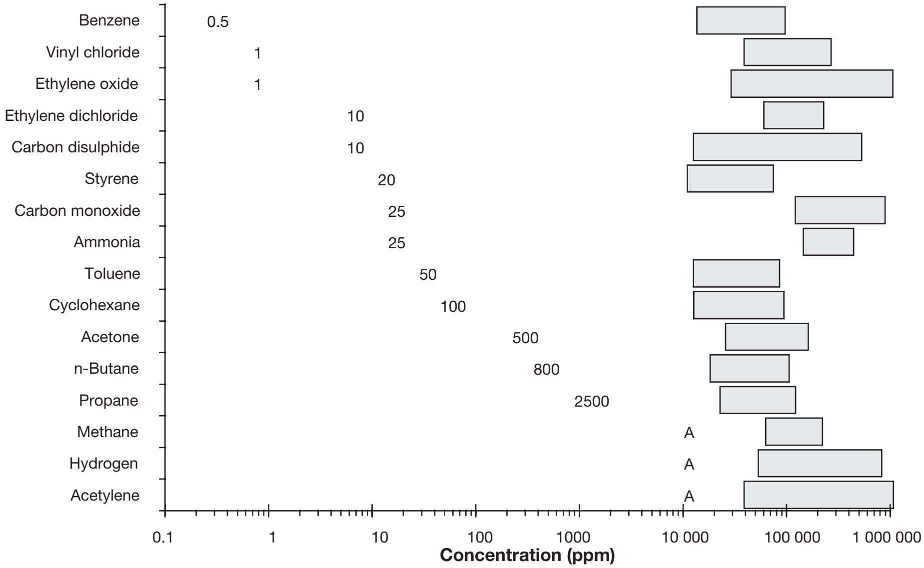


Figure 4.13 Exposure limits and explosive/flammable ranges (box) for common chemicals

A simple calculation shows that even a concentration of 1000 ppm of a solvent with a vapour density twice that of air is unlikely to sink to the ground. Imagine a million air molecules with unit density, with 1000 molecules of a solvent (10 times the occupational exposure limit for many solvents) with twice the vapour density compared to air. The density of the vapour-air mix is:

$$\frac{(999\,000 \times 1 \times 1000 \times 2)}{1\,000\,000} \begin{aligned} &= 1.001 \\ &= 0.01\% \text{ increase} \end{aligned} \qquad \text{(Equation 4.2)}$$

Now consider the ideal gas equation, PV = nRT, with the usual symbolic meanings ascribed to pressure (P), volume (V), moles (n), the gas constant R, and absolute temperature (T) in Kelvin (0°C is 273K). The air pressure at floor and ceiling is effectively the same, ignoring the weight of the air column in the room, and the volume of air is constant, so the 'nRT' side of the equation at floor and ceiling is the same (i.e. n1T1 = n2T2). Air temperatures of 20°C at the floor and 21°C at the ceiling give us:

T1 = 20°C = 273 + 20 = 293K at floor
T2 = 21°C = 273 + 21 = 294K at ceiling

giving

$$\frac{(n_2 - n_1)}{n_2} = 1 - \frac{T_2}{T_1} \qquad \text{(Equation 4.3)}$$

$$= 0.34\% \text{ change in density}$$

Just a 1°C temperature difference from floor to ceiling is going to produce much greater convective forces than the density of a vapour at 1000 ppm. This means that in most workplaces, normal air currents will mix the air and a blanket of 'heavier than air' vapour will not form on the floor.

4.8.3 GENERAL VENTILATION

General ventilation is aimed at reducing the concentration of a contaminant by adding fresh air to the workplace. It can be categorised as dilution ventilation and displacement ventilation. With dilution ventilation (discussed in Section 4.8.3.1), the contaminant is mixed with fresh air, diluting it. The air in the whole room may be mixed with the fresh air or a stream of air from a fan or an open window may perform the task more locally. Displacement ventilation is explained in Section 4.8.3.2.

If natural airflows are used to dilute contaminants, wind direction, wind speed and air temperatures are likely to have a great effect on the effectiveness of this approach.

4.8.3.1 Dilution ventilation

Dilution ventilation may be appropriate when:

- the air contaminant has low toxicity
- there are multiple sources
- the emission is continuous
- the concentrations are close to or lower than the occupational exposure limit
- the volume of air needed is manageable
- the contaminants can be sufficiently diluted before inhalation
- comfort (or odour) is the issue (in the absence of other contaminants)
- a spill has occurred and extended airing of the workspace is needed.

Example: a fan in a wall

Extractor fans are sometimes mounted above a workbench to remove contaminated air from the workbench. However, the air moves into the fan from all directions, in a collapsing hemisphere ('Reality' in Figure 4.14), and only a small amount of the contaminated air from the bench is extracted.

Dilution ventilation of contaminated air works in much the same way as pouring clean water into a jug of coloured water dilutes the colour. If the added water does not mix with the coloured water in the jug and just overflows, then the colour (contaminant) in the jug persists. If the jug contents are mixed during the process then the colour gradually fades as it is diluted. However, traces of the colour chemical remain long after all visible colour has been removed.

In many cases, poorly designed ventilation systems that aim to remove contaminated air ('Hope' in Figure 4.14) only dilute the contaminant, giving little local protection to the worker, but slowly clearing the air for the rest of the workplace.

Dilution ventilation calculations

The basic formula for dilution ventilation to describe the exponential reduction in contaminant concentration (C) with time is:

$$C = C_0 e^{-Rt} \qquad \text{(Equation 4.4)}$$

where:

C_0 = the initial contaminant concentration in air by volume
R = ventilation rate = Q/V
Q = airflow into the space ($m^3\ s^{-1}$)
V = volume of ventilated space (m^3)
t = time in seconds

Example: dilution ventilation calculation

In a room of 10 m^3, with 1000 ppm contaminant in the air, a diluting airflow of 0.1 $m^3\ s^{-1}$ is present. What is the concentration in the room after 10 minutes? Assume complete mixing.

C_0 = 1000 ppm
V = 10 m^3
Q = 0.1 $m^3\ s^{-1}$
R = Q/V = 0.1/10 = 0.01 s^{-1}
t = 10 × 60 = 600 s

$$C = 1000e^{-0.01\times 600} = 2.5 \text{ ppm} \qquad \text{(Equation 4.5)}$$

This is a small fraction of the original concentration.

The exponential decay of the contaminant with time is evident in Figure 4.15. The same data, plotted on a logarithmic scale, is a straight line. The slope of the line is the number of air changes per second, but if the time scale was in hours, then the slope would give the number of air changes per hour.

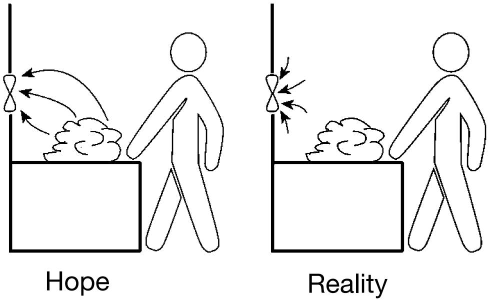


Figure 4.14 A fan in a wall—what was hoped for (left) and what actually happens (right)

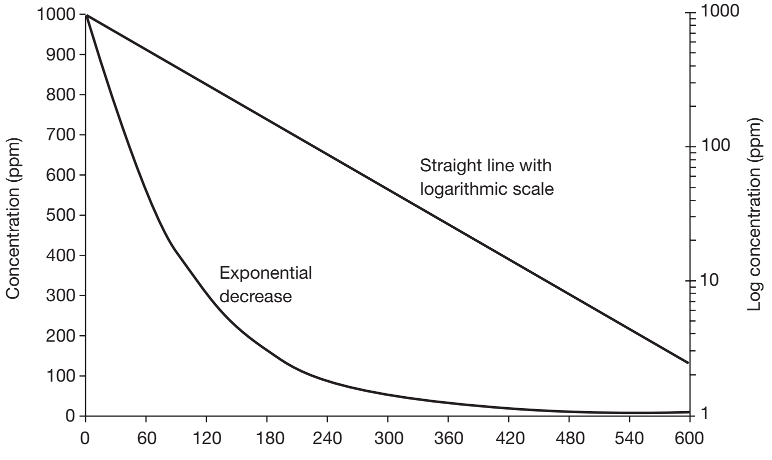


Figure 4.15 Dilution ventilation of linear and logarithmic scales

This calculation would underestimate the final concentration, as incomplete mixing always occurs. The flow should be increased by a safety factor, K, of 3 to 10, to calculate the expected concentration at a given time. K can be incorporated into the dilution ventilation equation as:

$$C = C_0 e^{-Rt/K} \qquad \text{(Equation 4.6)}$$

Many texts give tables of K as a 'mixing factor', but this does not take into account both the variability of local concentrations and degree of mixing (Feigley et al. 2002).

The degree of mixing of air in a room can make a difference to how well dilution ventilation works. For example, it is not uncommon for fresh air in an air-conditioned office to be introduced through slots in the ceiling, only to travel along the ceiling and then be exhausted, with little effect on air quality for the occupants. If the air inlet was directed downwards, then there could be complaints of draughts. By ensuring good mixing of fresh and contaminated air (while limiting draughts), the contaminated air is diluted and in the absence of more contaminant, the contaminant concentration will reduce exponentially with time.

To dilute the air after a spill, the required flow, Q , is:

$$Q(m^3 s^{-1}) = \frac{\text{Rate of evaporation } (mg\ s^{-1})}{\text{Density of liquid } (kg\ m^{-3}) \times TLV^{®}\ (ppm)} \qquad \text{(Equation 4.7)}$$

The required flowrate would need to be multiplied by the safety factor K (3 to 10) to account for incomplete mixing.

Some things to watch for in considering ventilation problems:

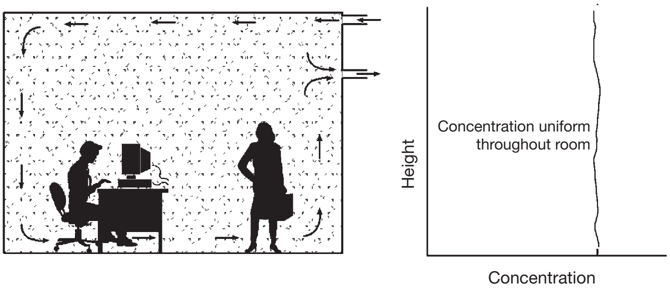
- Is the incoming or make-up air always clean?
- Where does the contaminated air go?

- If the ventilation is natural, what happens on still days or when the wind blows from another direction?

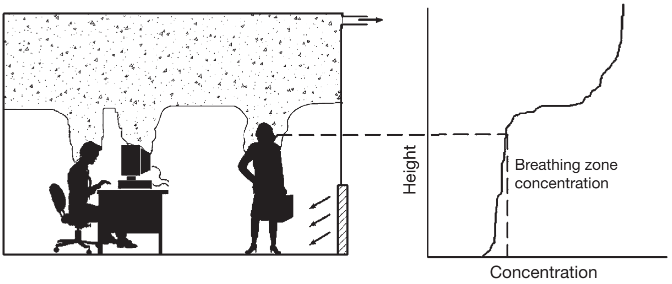
4.8.3.2 Displacement ventilation

Thermal displacement ventilation is a mature technology in Scandinavia but little known in Australia. Contaminated air is removed from the work area by the buoyancy plume of warmer air from people and work processes that are warmer than the surrounding air, as shown in Figure 4.16. Air around 2–3°C cooler is gently introduced near floor level to fill the area up to about 2–3 metres, similar to filling a pool with water. Special diffusers are used to ensure the airflow does not create draughts. Unlike conditioned air, which is usually cool and fed from vents in the ceiling, displacement ventilation works with natural convection patterns and can be much more efficient than dilution ventilation. Without a temperature gradient, the whole room has to fill to remove contaminated air.

In Figure 4.16, the contaminant concentration in the standing person's breathing zone (BZ) is more effectively reduced by thermal displacement ventilation than by traditional dilution ventilation.



Dilution ventilation



Thermal displacement ventilation

Figure 4.16 Dilution ventilation and thermal displacement ventilation (after Skistad 1994)

Use of displacement ventilation

Displacement ventilation works best when:

- the contaminants are warmer than the surrounding air
- the supply air is slightly cooler than the surrounding air
- the room is relatively tall (more than 3 metres)
- there is limited movement in the room.

If the ceiling height is less than 2.3 metres, the contaminated air is cooler than the incoming air, or there are draughts, displacement ventilation does not work as well. Cold windows or walls can create downdraughts, and hot spots in the sun can create local updraughts. Displacement ventilation is unsuitable for operating theatres (Friberg et al. 1996) and 'clean' rooms, as it tends to act against the sedimentation of particulates.

4.8.4 LOCAL EXHAUST VENTILATION

Local exhaust ventilation (LEV) aims to remove air contaminants before they have a chance to be inhaled. LEV principles have been known for over a century, but they are still poorly understood. An LEV system most commonly comprises a hood to capture and remove air contaminants, ducting to connect it to an air-cleaning system, a fan to move the air through the system and an exhaust stack outside the building to disperse the cleaned air.

In the workplace it is still rare to see good LEV design, particularly at the point at which contaminated air is captured, where there is a need for a hood to shape the flow of contaminated air and ensure its efficient capture. Any hood needs a predetermined airflow into it to make it work as designed, which in turn will determine the design of much of the rest of the LEV system. If the system is designed first and the hood is placed as an afterthought, then it is unlikely that air capture will be efficient. Fortunately, most poor designs are so obvious that advanced design skills are not required to spot the problems.

In Figure 4.17, workers are finishing fired earthenware with emery paper, producing dust containing respirable silica. The hoods are ventilated enclosures and have a glass top to let in light. Each hood is joined to a duct that is attached to a centrifugal fan. The exhaust from the belt-powered fan is cleaned by a cyclone. This is good design, but it would be even more desirable to clean the air before it reached the fan to lessen the wear on the fan blades and limit the deposition of particulates in the ducting.

Before an LEV system is designed, the potential for toxic exposure should be examined so that the required degree of protection can be estimated. This assumes an LEV system is the best approach, and that the hazard cannot be eliminated by substitution of the hazardous material or other process modifications, such as total enclosure of the process. If LEV is the preferred approach, then an appropriate hood is designed to capture the contaminated air and the airflow to make the hood operate is calculated. A large duct costs more and may result in settling of particulates in the duct. A small duct may result in large pressure drops or unacceptable noise and result in the system not being used. The duct may have bends and join other ducts and, like a highway, its size should increase gradually as the airflow increases so that the air velocity remains the same. The contaminated air is often filtered before being released into the atmosphere and the air cleaning device is usually placed before the fan that sucks the air through the system, so that the fan is protected.

Once the air has passed through the fan, it is pushed through a stack under pressure. At this point, leaks do not just make the system less efficient, but can cause contaminated air to re-enter the workplace if the fan is inside the building. The height of the stack

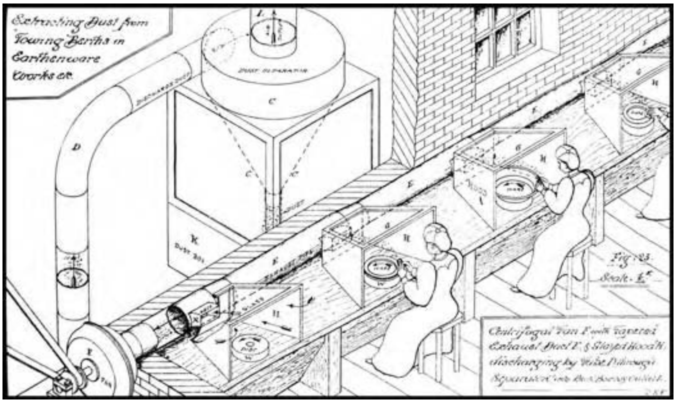


Figure 4.17 LEV system in a pottery (HMSO 1907)

should take into consideration buildings and structures both upwind and downwind of the stack to ensure the air released does not enter other inhabited buildings.

Lastly, the type and size of the fan are chosen to produce the desired flow into the hood and overcome the pressure drops through the system. The components of an LEV system will now be considered in their design order.

4.8.4.1 Hoods

Hoods are the most important part of an LEV system, as a poorly designed hood limits the performance of the whole system. It is not uncommon to see a complex system installed and to have a woodworking machine or other source of air contaminants attached to the system with little regard to how effectively the system will capture the contaminated air from that source. The most efficient hoods smoothly accelerate air from near stationary to the duct velocity with few eddies or changes of direction. It is difficult to capture billowing contaminants without first enclosing them in a larger volume. Similarly, high-velocity air contaminants from operations like grinding are usually intercepted and the residual contaminants then captured.

Some simple principles can be applied to make hoods more effective:

- reduction of the source of emissions—such as closing the lid on a vessel, making the process wet to reduce dust, or using premixed formulations to limit the dustiness of a toxic component
- placing the hood as close as possible to the source, preferably enclosing it
- if the source includes fast-moving particles, positioning the hood to receive those particles
- specifying a 'capture velocity' at a point greater than the particle velocity
- locating the hood so that a line from the operator's face to the contaminant source leads directly towards the hood.

4.8.4.2 Capture zone and capture velocity

A useful concept is to determine the zone where the air contaminants are generated and need to be captured. This in turn requires estimates of the air velocity needed at the edges of the zone to ensure this occurs. In Figure 4.18, the air trajectories into a slot hood are visualised with a smoke tube. Chalk lines show the flow lines into the hood and a capture zone for an air speed of 0.25 m/s (measured with a hot wire anemometer) is shown by the chalk line intersecting the air trajectories.

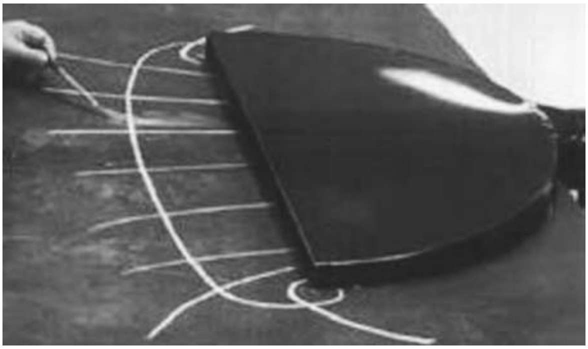


Figure 4.18 Flow lines and capture zone for a slot hood

Air is sucked from all directions into the hood and almost as much air enters the hood from behind it as from in front of it.

The 'stopping distance', S, is a useful concept in estimating how far a particle will travel before it can be affected by airflow into a hood (Figure 4.19). For particles with the density of water (unit density) that can be inhaled (generally <100 μm diameter) and travelling at 10 m/s (at NTP), the stopping distance varies from 13 cm at 100 μm diameter to 88 μm at 1 μm diameter. (NTP, or normal temperature and pressure, is defined as air at 20°C [293.15K] and 1 atmosphere [101.325 kPa *or* 14.7 psi].)

Particles greater than 100 μm diameter tend not to be inhaled and can move some distance before the viscous drag from the air slows them. They may be more of a housekeeping problem than an inhalation issue. The stopping distance of very heavy (lead) or light (glass micro-balloon) particles has to be scaled by their density.

4.8.4.3 Flanges

Flanges are an integral part of a hood which help shape the airflow into the hood and reduce the amount of uncontaminated air entering the hood. Many hoods are inadequately shaped, making them very inefficient at capturing air contaminants. The most efficient hoods avoid eddies, so that most of the suction accelerates the contaminated air to the duct velocity smoothly and with few eddies. However, making a hood very efficient at collecting contaminated air may obstruct work and lead to the hood's removal.

Close observation and investigation of work practices is usually needed to design a hood that is both efficient at collecting contaminated air before it is inhaled and is acceptable in the workplace.

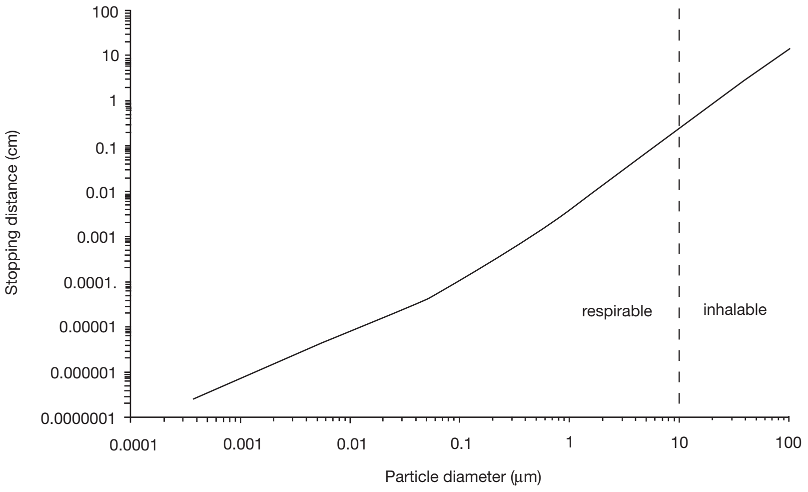


Figure 4.19 Stopping distance of unit density particles

In Figure 4.20 the flange stops most clean air from behind the hood from being captured, and so extends the range of the hood to capture more contaminated air.

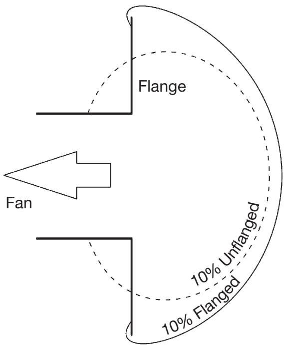


Figure 4.20 Effect of flanges on capture of contaminants (after Alden and Kane 1981)

4.8.4.4 Slots

Where the contaminant is not a point source—such as a drum filling operation or dipping tank—long hoods with slots can make capture more efficient. The hood may be straight or curved but, most importantly, it should be very close to the source of emission, as effectiveness drops rapidly with distance. For a long tank, a slot hood along each side can be effective (Figure 4.21), but this may create a dead zone down the middle of the tank that still allows contaminants to escape. If you cannot predict which way contaminated air will move, then there is a design problem.

Figure 4.21 Slot hoods along the length of a tank

4.8.4.5 Enclosures

If it is practicable to enclose an emission source or imperative that a high level of containment of the emission is obtained, a hood that encloses the emission can be very effective, particularly if there are draughts in the workplace. The hoods shown in Figure 4.17 are of the type called enclosure. Enclosures surround much of the task, giving high levels of containment and some resistance to room draughts. Fume cupboards are also enclosures.

4.8.4.6 Fume cupboards: a special type of enclosure

Fume cupboards are a special type of enclosure found in laboratories. Good designs have been available for 50 years, but design flaws can still limit a fume cupboard's effectiveness. A respirator may reduce air contaminants by a factor of 10 to several hundred, but even a poorly designed fume cupboard may reduce toxic exposure by a factor of 1000 or more. The slightest reverse airflow will limit the effectiveness of a fume cupboard, however, while the best design would reduce the user's exposures by yet another factor of 10 or 100.

It is easy to demonstrate air flowing into a fume cupboard with a smoke tube. However, smoke puffed near the front sill or just inside the sash will often reveal a small quantity of smoke moving outwards due to the airflow being unable to follow the contours of the sill or sash. This results in small but significant amounts of contaminated air moving towards the front of the sill and sash, which may be released by the air swirling in front of the fume cupboard operator—like the smoke of a barbecue. The problem is further confounded by the air wake left by passers-by and the thermal plume of warm air generated by the fume cupboard operator. This results in the degree of protection offered by the fume cupboard being lowered and preventable toxic exposures occurring.

In Figure 4.22, the image to the left shows that the combined effect of a thermal plume from the person's body, body wake and reverse airflow induced by the fume

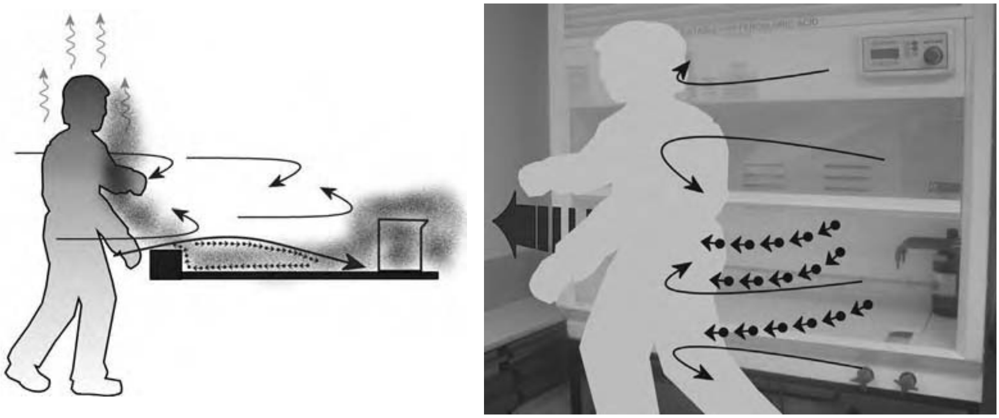


Figure 4.22 Complex airflows in front of a fume cupboard increase the exposure of the user

cupboard sill ensure that toxic exposures will occur. The image to the right shows the effect of passing traffic at 0.9 m/s overpowering the containment of a fume cupboard.

Tracer gas studies (Johnson & Fletcher 1996) on fume cupboard containment with the sash at various heights demonstrated that for a modern aerodynamically-designed fume cupboard the breathing zone concentration was highest when the face velocity at the sash opening was between 0.4 and 0.6 m/s. AS 2204:8 (Standards Australia 2001) for fume cupboards recommends a face velocity of 0.5 m/s, which is in the middle of this range. Many fume cupboards currently in use in schools, industry and tertiary institutions would have been purchased many years ago and would not have aerodynamic surfaces, thus not reaching optimal flow pattern. Work practices such as leaning one's head against the sash to see inside greatly increase toxic exposures.

4.8.4.7 Push-pull ventilation

Push-pull ventilation uses a combination of traditional hoods and jets of air to blow contaminants into the hood from a greater distance than could be managed by suction. It was probably developed in the late 19th century and rediscovered in the 1960s. It can be very successful for large rectangular areas like tanks, where there is slot ventilation at one end and a jet of air blown across the tank from the opposite side. It can also be used to avoid much of the swirling of air that occurs in front of a worker.

In Figure 4.23, push-pull ventilation is used to reduce white phosphorus exposure to a match dipper. The worker is dipping matches in a basin of highly toxic white phosphorus and a curtain of air is moving over the surface of the basin towards the hood at the back of the workbench.

Extraction flows must significantly exceed supply air in push-pull systems, as the air jet entrains a large volume of air. Their major drawback is when the air jet is interrupted when the tank is accessed to remove or add objects, and the air and any contaminants are deflected by the object into the workplace.

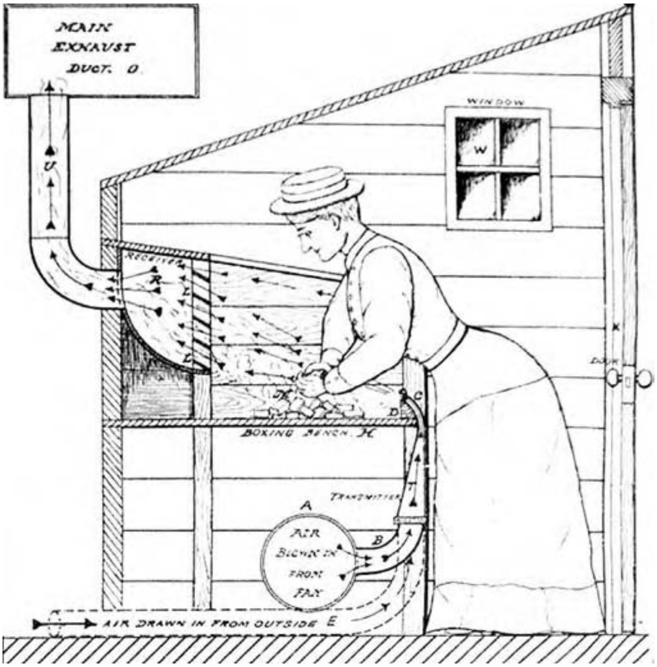


Figure 4.23 Push-pull ventilation (HMSO 1907)

4.8.4.8 Air-assisted hoods

Various approaches have been taken to achieve directional airflow with hoods to extend their range. There has been some success with Aarberg-type hoods.

In Figure 4.24, the increase in capture range from a simple flanged circular hood (left) and Aarberg circular hood (right) is shown. The circumferential jet of air used by the Aarberg circular hood (right) entrains clean air which would otherwise be captured, leaving a tunnel in front of the hood to capture contaminated air from a greater distance. A long slot version of the hood is also possible.

Air-assisted hoods largely overcome the problem found with push-pull ventilation when objects are raised from dipping tanks, as there is no jet of air directed at the contaminated object. However, if the air jets designed to entrain clean air also entrain some contaminated air, then they will spread this contaminated air about the workplace. Air-assisted hoods may also be unacceptably noisy.

4.8.4.9 Hand tools

Increasingly, pneumatically powered and electrically powered hand tools are being designed with provision for dust extraction. This is particularly important in the construction industry, where concrete dust produces toxic silica dust, and in the woodworking industry, where wood dusts from both hardwoods and softwoods have been associated with an increase in nasal cancers.

Often all that is required is the connection of an appropriate vacuum cleaner to the tool to reduce the dust. A reduction of inhalable dust of up to 98 per cent can be

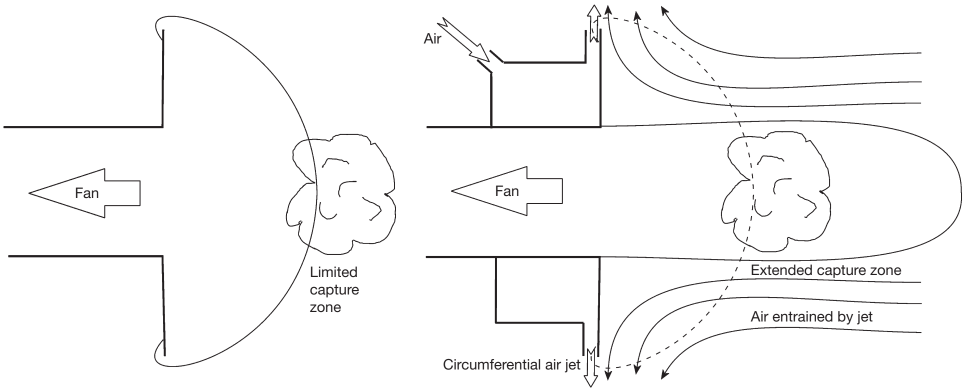


Figure 4.24 Aarberg-type hoods (right) can greatly extend the capture range of a simple flanged hood (left)

expected, but less effective reductions occur with very fine respirable particles. Respirable dust is invisible to the naked eye and tends not to deposit in the nose or throat but in the lungs. Some domestic vacuum cleaners may have HEPA filters, but they are not designed to meet industrial standards and have been found to pass up to 50 per cent of particles 0.35 μm in diameter (Trakumas et al. 2001). (HEPA, or high efficiency particulate air, filters remove 99.97 per cent of particulates 0.3 μm or larger.) Toxic dusts collected by a vacuum cleaner can also become a source of air contaminants when they are re-suspended inside the vacuum cleaner, particularly with cyclonic and wet vacuum cleaners.

4.8.5 DUCTING

Ducts in LEV systems may be viewed as highways, with merging lanes and sweeping bends. If there are unnecessary or sharp bends, then greater pressure drops will occur and less suction will be available to power the hoods and energy is wasted. If sections of duct bend or join at 90°, there will be increased turbulence where the airflows intersect. Airflow is preferably smooth with no abrupt changes in direction and speed. It is common for a good design to be impaired on installation with sharp bends and tortuous paths around beams that were not accounted for in the plan, which encourages the deposition of particulates. No great engineering skills are needed to recognise most bad duct installations.

4.8.5.1 Duct transport velocity

If the air velocity in a duct is too low, then particulates will settle in straight sections of duct and clog it. If the duct velocity is too high, the noise may be unacceptable and large pressure drops may develop, requiring a larger fan. The minimum design duct velocities in Table 4.3 are based on the ACGIH® recommendations in *Industrial Ventilation* (ACGIH® 2004).

Table 4.3 Duct transport velocities

Type of contaminant	Examples	Design velocity (m/s)
Vapours, gases, smoke	All vapours, gases and smoke	Usually 5–10
Fumes	Welding fumes	10–12
Very fine light dust	Cotton lint, wood flour	12–15
Dry dust, powders	Fine rubber dust, wood shaving	15–20
Industrial dust	Grinding, buffing, masonry, quarry dusts	17–20
Heavy dust	Wet sawdust, heavy metallic dusts	20–22
Heavy or moist dust	Sticky dusts, heavy dusts with chips	>22

Ducts should be provided with 'cleanout ports' at strategic intervals to enable the removal of deposited particles and condensed vapours, and to permit inspection of the duct for clogging and corrosion.

4.8.6 AIR TREATMENT

Air treatment to remove contaminants is becoming more important as environmental awareness increases. It is no longer acceptable to simply exhaust contaminated air into the environment. There are many technologies available; for some industries, like power stations, the installations can be huge. In principle, contaminants can be considered as either particulates or gases.

For gases and vapours, molecular processes have to be used—absorption, adsorption, condensation and incineration. For particulates, a range of filtration and inertial separation technologies is used, including cyclones and inertial separators, electrostatic precipitators and fabric filters. Most texts on industrial ventilation will give a good introduction to this topic, a detailed treatment of which is beyond the scope of this book. Suppliers are good sources of information on selection of the appropriate technology.

4.8.7 FANS

Poor LEV design may have a significant effect on the choice of fans, and on operating cost. Bad LEV design costs money initially, more money to run, and may do little to protect the worker.

The relationships between the flowrate through a fan (Q), the pressure drop (p) it can produce, the fan speed (n) and size (d) are given in terms of fan laws (Osborne 1977) in Table 4.4. This table also shows how small increases in flow (Q) to compensate for poor hood design can result in large increases in fan motor size and power consumption.

Table 4.4 Fan laws

Law	Formula	Comment
Volume flow (Q)	$Q \propto d^3 n$	The flow varies with the fan speed, but increases with the cube of the fan diameter.
Fan pressure (p)	$p \propto d^2 n^2 \rho$	The pressure drop the fan can produce varies with the square of both the fan diameter and speed.
Fan power (P = p × Q)	$P = pQ \propto d^5 n^3 \rho$	Derived from the first two laws. The fan motor size and power bill will vary enormously with the fan size and fan speed.

Source: Osborne (1977)

Once the airflow (Q in m^3/s) needed to make a system work, and the total pressure drop (p in Pa) in the system, are calculated (these calculations are beyond the scope of this book), an appropriate fan to make the system work as designed is required. The size of the fan motor is simply p x Q (in watts), with an allowance for the efficiency of the fan in moving air and the fan motor, collectively about 60 per cent. Thus to move 10 m^3/s of air with a pressure drop of 250 Pa (about 1 inch of water) for the whole system, the fan motor size would have to be:

$$\text{Power of fan motor} = \frac{10\ (\text{m}^3\text{s}^{-1}) \times 250\ (\text{Pa})}{0.6\ (\text{overall efficiency})} = 4\ \text{kW} \qquad \text{(Equation 4.8)}$$

In practice, 4.5–5 kW would be chosen to allow for drops in efficiency with time.

There are many types of fans used for industrial ventilation, but in small industry three types dominate—axial fans, forward-bladed centrifugal fans and radial-bladed centrifugal fans. Large axial fans are often used to move large volumes of air against a small resistance. Some axial fans are also used in LEV systems, being hidden inside a duct. For many systems, good flows can be obtained for long runs of ducts and air-cleaning devices with a forward-bladed centrifugal fan. If the air is contaminated, then a less efficient but more robust radial-bladed centrifugal fan is required.

A ventilation system is characterised by a system curve (Figure 4.25) relating the pressure drop (p) and the airflow (Q). This is parabolic, with the pressure drop increasing with the square of the flow. The fan performance is also shown by the fan curve and, at a given speed, it will produce a certain airflow against the resistance of the air-cleaning devices, ducts and hoods on the suction side and the ducts and stack on the exhaust pressure side. Each type of fan will have a set of fan curves for different fan speeds. (These curves are published by fan manufacturers.) It is usual to select a point on the fan curve where the mechanical efficiency is highest.

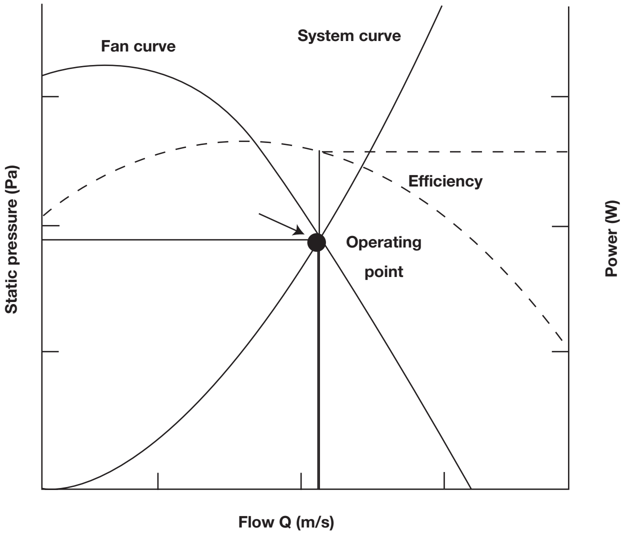


Figure 4.25 Fan and system curves (after McDermott 1976)

4.8.8 STACKS

A stack serves to disperse the air outside a workplace from a ventilation system. Good design limits the amount of air that re-enters buildings and should not incorporate structures that cap the stack to reduce ingress of rain, as they will limit dispersion or even direct foul air back into a building.

A rule of thumb is that the stack should be 2.5 times higher than the tallest building (Hughes 1989). An alternative rule is that the stack height (H_s) should be

$$H_s = H + 1.5D \qquad \text{(Equation 4.9)}$$

where:

H = the height of the building, and
D = the lesser of the building height and the maximum length of the building across the prevailing wind.

Sometimes scale wind-tunnel studies are needed, particularly if the building has a courtyard. Releasing smoke into the system from a smoke generator will often reveal inadequacies in stack height and location.

4.8.9 MEASUREMENT

Quantitative measurement of airflows can be performed with either vane or hot-wire anemometers. **Vane anemometers** are mechanical and have a start-up speed of around 0.2 m/s; they are often used for measuring the face velocity of fume cupboards and for room outlets in air-conditioning systems, as they can give an air speed averaged over a few seconds and the area of the vane. **Hot-wire anemometers** are generally considered unsafe in explosive atmospheres unless certified otherwise, but are useful for general industrial ventilation work and can measure lower air speeds than a vane anemometer.

Pitot tubes give absolute measurements of velocity pressure, and are usually used to estimate the airflow in ducts, but they are cumbersome.

The cheapest and most useful tool for investigating industrial ventilation systems is the **smoke tube**. Here, a chemical in the tube reacts with moisture in the air to form a white smoke, which enables the visualisation of airflows and the estimation of both direction and magnitude of even the smallest air movements (Figure 4.26).

Smoke tubes are particularly useful in demonstrating the limitations of a hood in capturing air contaminants and for showing airflows from behind a hood. They can also be used to visualise airflows through windows and doors—sometimes the flow can be in one direction at the top of a door and the opposite direction at the bottom. It is also possible to use a fume cupboard to estimate room air speeds by estimating the time a puff of smoke takes to travel 1 metre. This makes smoke tubes useful in indoor air-quality investigations.

For a fume cupboard it is usually possible to demonstrate reverse airflows by puffing smoke just inside the sash and on the working surface near the front of the fume cupboard, as shown in Figure 4.27.

The flow at the centre of the face of a fume cupboard is often measured, but this does not reveal the limitations in containment of the fume cupboard. Investigating the flow *into* the fume cupboard answers the wrong question, as it is the minute flows *towards the front* of the fume cupboard that determine its overall performance. These forward flows place contaminated air at a point where it may be entrained in the swirling air in front of a person using the fume cupboard. The front of the fume cupboard is also more exposed to room draughts. The question that needs to be asked is whether contaminated air *inside* the fume cupboard is contained. Small reverse airflows near the face of the fume cupboard (at X in Figure 4.27) lead to significant loss of containment in almost all fume cupboards. This is easily demonstrated with a smoke tube. This route of exposure is important for highly toxic chemicals.

4.8.10 NOISE CONTROL IN VENTILATION SYSTEMS

A common reason for ventilation systems failing to provided the expected protection is that they are too noisy and get switched off. Often the fan is the source of the noise, which travels along the system like sound through a large trumpet. The predominant problem may be the ‘passing frequency’ of the fan blades. Mechanically isolating the fan from the duct with a flexible join (at least a duct diameter away is desirable) can do much to reduce this noise. However, if the join is too floppy it will vibrate and increase the noise level. A fan placed too close to a bend, or wrongly sized for the job, can easily produce 10 dB extra noise. Low frequency noise generated by air-handling systems is usually the hardest to attenuate.

Sometimes ducting is suspended from a roof, when vibrations in the duct can make the whole roof or other large surface vibrate. Choice of a duct suspension system that reduces this ‘flanking’ can make a marked effect on the noise levels in the workplace.

Noise predictions are possible for industrial ventilation systems, but the calculations

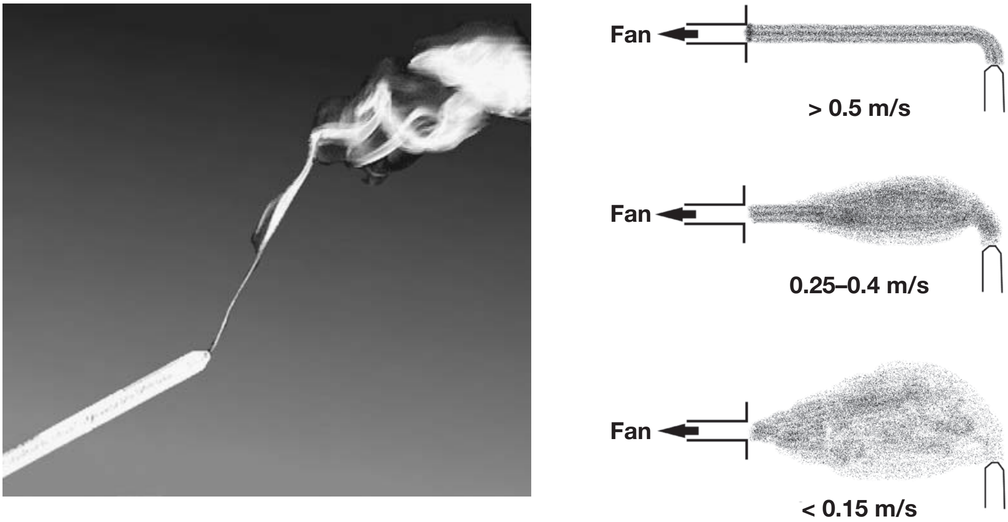


Figure 4.26 Smoke tube and its use in estimating air velocity (right—after McDermott 1976)

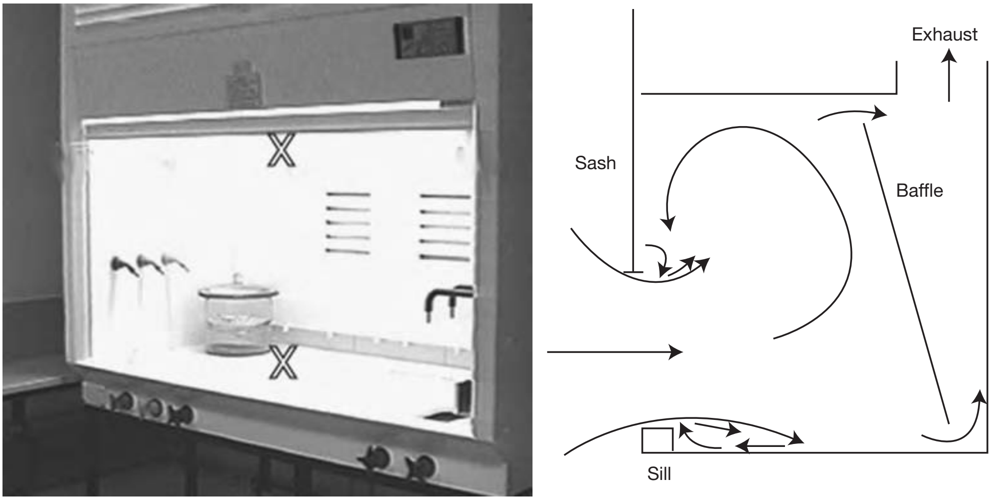


Figure 4.27 Potential loss of containment of a fume cupboard at 'X'

are complex, for the degree of turbulence, stiffness, reflections and openings all affect the amount of noise. In a straight duct, the noise level varies with at least the fifth power of the air velocity (Sharland 1972), so that for a given airflow, very small changes in duct diameter can have a large effect on noise levels. Small increases in duct roughness can add 5 dB or more to the noise.

4.8.11 INDUSTRIAL VENTILATION SOFTWARE

There are a number of software packages to assist industrial ventilation design. They are not a substitute for knowledge, but can reduce the tedium associated with manual calculations. Some are commercial LEV software, such as HeaVent by Dr Steven Guffey, which is based on a wealth of experimentation and theory published in the *American Industrial Hygiene Association Journal* (a demonstration version is available at <www.industrialventilation.net>). For major general ventilation projects and research, computational fluid dynamics (CFD) packages such as FLUENT® and CFX® are popular, but require years of training to produce sensible results. There are also special CFD packages for ventilation like FLOVENT® (<www.flovent.com>), for which a free demonstration version is available.

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5. Aerosols

Geoff Pickford FAIOH and Dr Brian Davies FAIOH

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5.1 INTRODUCTION

This chapter considers aerosols from the perspectives important to the H&S practitioner, and includes:

- information on different kinds of aerosols
- work situations where aerosols are commonly encountered
- what happens to inhaled aerosols in the human respiratory system
- how to assess various kinds of workplace aerosol hazards
- an historical review, so that the H&S practitioner knows how important the aerosol problem has been in the past.

5.2 WHAT ARE AEROSOLS?

The term 'aerosol' applies to a group of liquid or solid particles suspended in a gaseous medium, usually in the range of 0.001 to 100 µm in size (1000 µm = 1 mm). Naturally and artificially produced aerosols are found in ambient and industrial air environments and vary greatly in size, density, shape and chemical composition. For example, the shape of aerosols includes spheres (water or oil droplets and welding fume), cylinders (asbestos and glass fibres), crystalline particles (crystalline silica), regular and irregular particles (fly-ash and road dust). The term 'particle' implies a small discrete object, and 'particulate' indicates that the material has particle-like characteristics.

There is no simple system for classifying aerosols found in the workplace based on the nature of the aerosol, its toxic effect or particle size. All are important for different reasons. Some exert their toxic effects in the nose, throat and upper airways, others in the lung, and for some the lung is not the ultimate target organ but merely the route of entry. Further, some inhaled aerosols can cause more than one effect depending on the amount to which a worker is exposed (i.e. the dose).

5.2.1 DUST

Dust usually comprises solid particles generally greater than 0.5 µm in size, formed by crushing or other mechanical forces on a parent material. Dust is found everywhere, including all workplaces, and has remained one of the most intractable of workplace problems since metal ores were first mined. Operations carried out in today's industrial workplaces—mining, crushing, sieving, milling, grinding, planing, sawing, sanding, machining, pouring—all contribute to particle generation. Particles generated in one workplace can become airborne dusts that are carried into other working locations. While many of these dusts are relatively harmless, causing only transient irritation, some give rise to lung fibrosis, others to carcinoma, bronchitis, asthma or other lung disorders.

5.2.2 FUME

Fume is produced as the result of condensing vaporised materials, usually metal, and represents particles less than 0.05 µm in size, even though these particles generally agglomerate. Smelting, thermal cutting and welding operations all produce fume. The measurement of fume is conducted using AS 3853.1 (Standards Australia 1991a), which is in the process of being revised as this book is being published. The Australian Standard® describes the use of inhalable sampling devices suitable for insertion behind protective face shields normally worn by welders. The companion standard AS 3853.2 (Standards Australia 1991b) deals with the measurement of gases relating to welding. 'Diesel fume', as it is commonly and incorrectly known, is actually a particulate which is present in many environments as a result of diesel engine-powered vehicles and plant, and is discussed in Section 5.7.

5.2.3 MIST

Mist or fog is a liquid form of aerosol comprised of liquid droplets. Examples of mists are oil mists, chemical mists, and water mists contaminated with various chemicals.

5.2.4 SMOG

Smog is an aerosol consisting of solid and liquid particles, created generally by the action of sunlight on various vapours (refer to Chapter 7, Gases and Vapours).

5.2.5 SMOKE

Smoke is a solid or liquid aerosol which is the result of incomplete combustion, and most smoke particles are sub-micrometre in size.

5.3 AEROSOLS AND THE WORKPLACE

What kinds of aerosols might the H&S practitioner encounter in the workplace? One major source is from naturally occurring and synthetic manufactured materials of **inorganic mineral origin**. Coal, quartz-bearing rock and toxic metal dusts (e.g. lead) commonly associated with mineral extraction and processing industries are all significant sources of workplace dust. Many metal manufacturing and processing industries give rise to dusts and fumes of **toxic metals** (lead, zinc, copper, arsenic). Today, many people are potentially exposed to dust from **construction and demolition activities**. **Asbestos** can still be present in some 'asbestos-free' friction materials manufactured overseas (e.g. brake linings), despite the ban on all types of asbestos importation. Workers are potentially exposed to asbestos fibre in the asbestos removal industry. **Synthetic mineral fibres** used in insulation and fire rating provide another source of workplace dust exposure, but they are not toxic like asbestos, except that various specific types of synthetic mineral fibres are classified as 'possibly carcinogenic to humans'. Refer to Section 5.9.1 for more detailed information.

Naturally occurring organic dusts are common in some workplaces. Rural workers are exposed to natural dusts of grain. Sugar mill workers may be exposed to dust from bagasse, which is the waste cane after sugar has been extracted. Downstream processing industries expose workers to dusts containing wood, cotton, paper, felt, fur, feathers and pharmacologically active plant materials.

Within industrial manufacturing processes, the H&S practitioner can encounter **manufactured dusts** from a range of plastic polymers—epoxies, polyvinylchloride, acrylates, polystyrene, etcetera. They are found in industries as diverse as foundries, plastic pipe manufacture, packaging, surface coating industries and dental laboratories. The wide spectrum of dusts and the ways they occur in different workplaces provide a constant challenge to the H&S practitioner to devise various strategies for their control.

From the point of view of the H&S practitioner, the two factors important for assessing the impact of inhaled aerosols in the workplace are:

- chemical composition of the aerosol
- particle size.

Composition and **particle size** are important in the way an inhaled aerosol affects the worker, because together they govern how much of a material actually enters the body, where it finally deposits and what sort of toxic effect it can exert.

5.3.1 CHEMICAL COMPOSITION OF THE AEROSOL

It is known that different kinds of aerosol can cause different effects on health. Thus the composition of the aerosol, principally its chemical composition, is obviously important. In some cases, the toxic effect caused by the inhaled particles or dust occurs quickly (e.g. within a few hours). This acute toxic effect is easy to associate with exposure to the inhaled aerosol.

In other cases, the effect of inhaling the aerosol may be a chronic effect and not appear for many years following exposure. It then becomes difficult to make an association between the inhaled aerosol and its effect. This long latency period has often made it difficult to establish causal links between particular aerosol exposures and disease. Of course, it can also lead to a false sense of safety in dealing with such aerosols. To be able to assess any likely health impact of the aerosol in the workplace air, the H&S practitioner needs to know something of its identity.

The following examples highlight the need to identify the aerosol correctly. Some aerosols, dusts or particulates are acute respiratory hazards which can cause immediate or short-term health issues, some are chronic respiratory hazards which can take years to develop, some are sensitisers that can cause increasing symptoms on further contact and some are not particularly hazardous at all.

- Welding fume may consist mostly of relatively non-toxic iron oxide combined with a small proportion of highly toxic cadmium or other metal fume which has acute effects (refer to Chapter 6, Metals).
- Airborne asbestos fibres present significant chronic respiratory hazards; airborne synthetic mineral fibres do not. Both types of fibre can be present in some workplaces.
- Airborne quartz dusts are far more hazardous than limestone dusts, because quartz

causes silicosis, which is a chronic disease, whereas limestone is innocuous.
- Many wood dusts, and sap, latex and lichens associated with wood can lead to skin irritation, sensitisation dermatitis, and respiratory effects such as rhinitis, nose bleeds, asthma and other allergic reactions. However, toxic activity is determined by the species of tree, of which some are more toxic than others, even leading to nasal cancer in the case of some hardwood dusts.

In some cases, the identity of an aerosol can be obtained directly from a material safety data sheet (MSDS), particularly where there is no chemical transformation in processing. For example, in manufacturing lead accumulator batteries, it would be reasonable to expect to find lead-containing dust in the workplace atmosphere. But the identity of the hazardous particulate is often not clear. If unsure, seek expert advice and analysis from a suitable laboratory. On occasions, workplace aerosols will contain more than one hazardous component (e.g. refractory ceramic fibre and cristobalite, or coal dust and quartz). Both may need to be monitored. The most cost-effective control solutions are possible only if the identities of hazardous materials are known. Costly solutions may otherwise be based on wrong information.

Most inhalable dusts are toxic to other organs rather than to the lung. Uptake may be directly via the bloodstream in the lung, or by secondary absorption in the gut. Solubility in the gut may be low while lung absorption is very high. Examples include:

- soluble toxic salts such as nicotine enter via the lung and gut and target the brain
- toxic metals such as arsenic, zinc, cadmium or lead may enter primarily via the lung and target various other organs.

5.3.2 PARTICLE SIZE OF AEROSOLS

Aerosols generally found in the workplace vary widely in size, as shown in Figure 5.1. Workplace dusts of interest range in size from larger than a human hair (which is approximately 30–100 µm in diameter), to microscopic dusts measuring less than 1 µm. Particle size is important for two reasons. First, particle size determines how long a particle remains airborne and hence how far an aerosol cloud will disperse in a workplace before settling. This factor may influence choice and effectiveness of control strategies.

Second, the effects on health that many aerosols exert depend on their site of deposition. The site of deposition depends largely on the size of a particle, or more correctly, its aerodynamic settling velocity. Large particles (up to several hundred micrometres in diameter) settle in the nose and throat and may cause their effects at these sites. Smaller particles are collected in the upper airways (the bronchi and bronchioles) from where they can be cleared by the mucociliary escalator (cilia beating in an upward direction). The very small particles, termed respirable dusts and generally smaller than around 3–5 µm in dimension, penetrate right to the alveolar gas exchange region of the lung, from where they are only very slowly cleared.

Consequently, any assessment of an aerosol made in a workplace which reflects a disease risk must take into account particle size. Different sampling methods are available to achieve this.

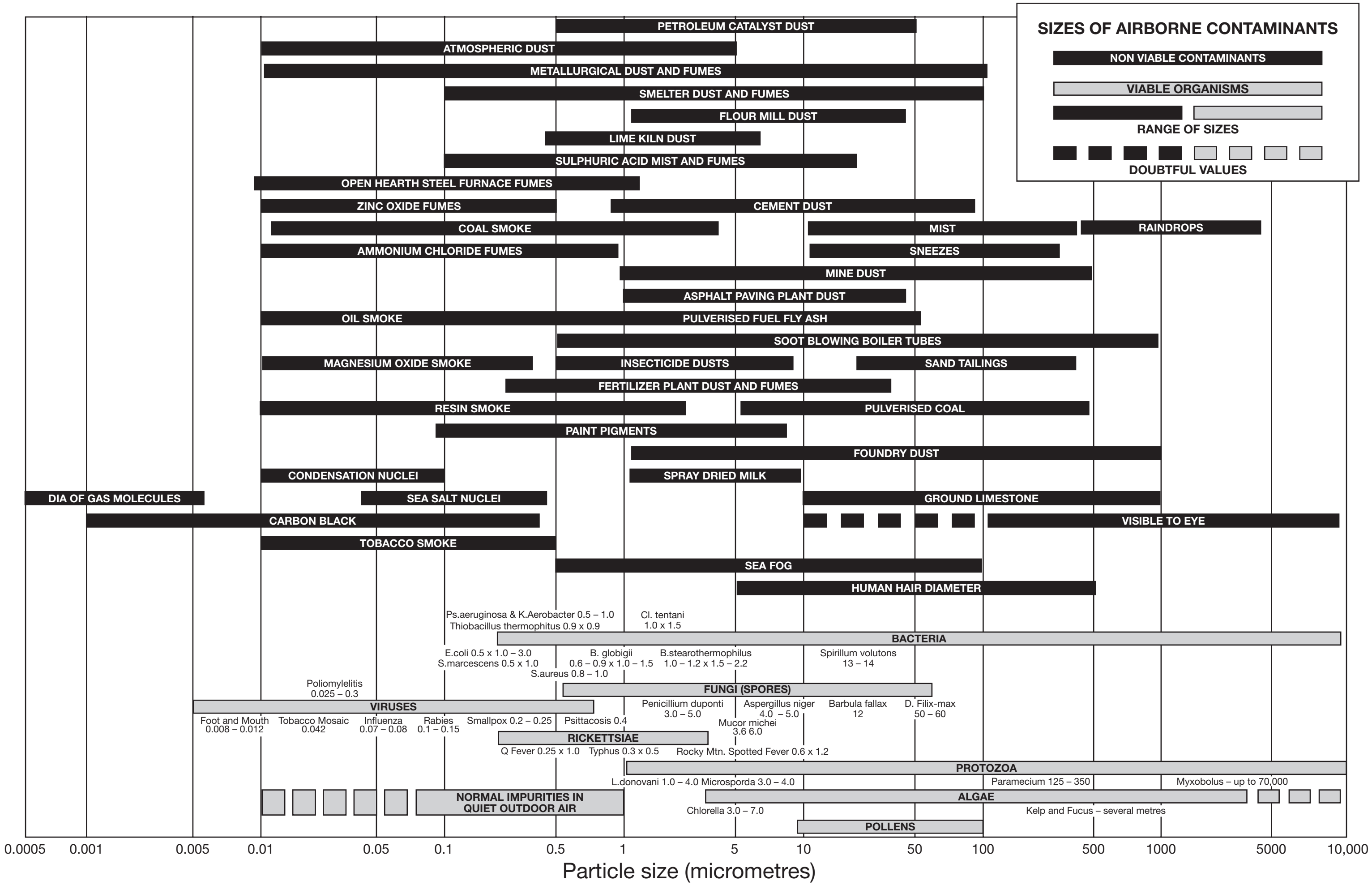


Figure 5.1 Sizes of various dusts significant in the workplace

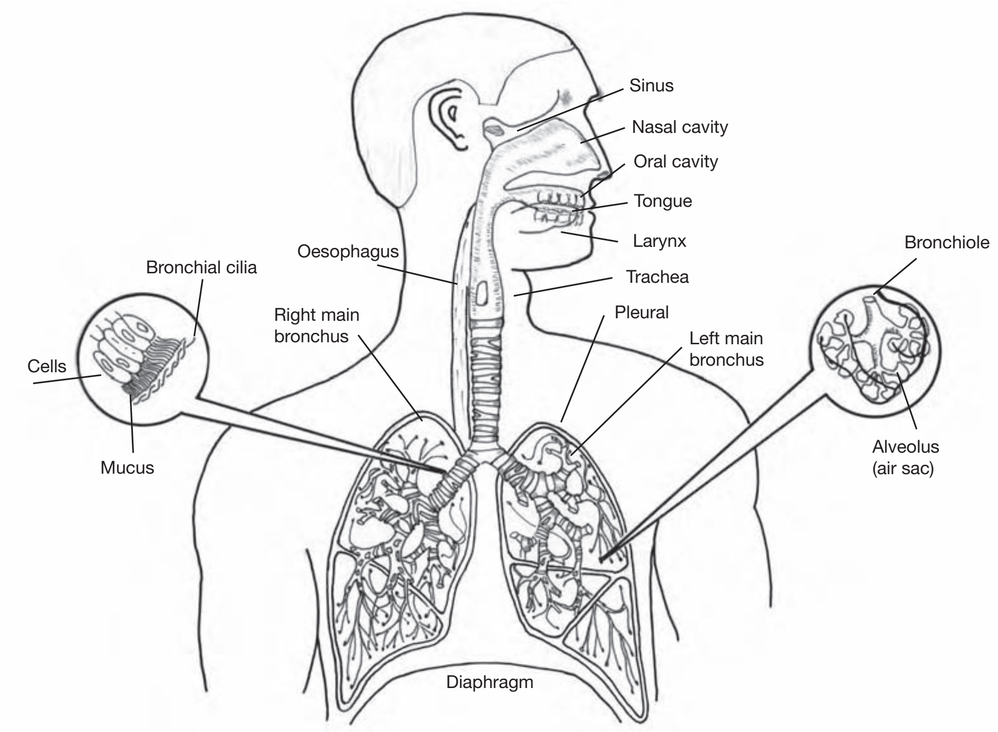


Figure 5.2 Basic structure of the respiratory system

Figure 5.2 shows, in simplified form, the basic structure of the human respiratory system and each of the components. The figure also assists in understanding a number of concepts used for dust deposition and measurement, as follows:

1. **inhalable mass**—for those materials which are hazardous when deposited anywhere in the respiratory tract
2. **thoracic mass**—for those materials which are hazardous when deposited anywhere in the lung or gas exchange region
3. **respirable mass**—for those materials which are hazardous when deposited in the gas exchange region.

Of these three descriptions, only (1) and (3) are of significance here because they are the only ones which can be easily measured. Both are examined in more detail when inhalable and respirable dusts are discussed. The Australian Standard® AS 3640 (Standards Australia 2004c) uses the term 'inhalable dust', for what was formerly known as 'inspirable dust'.

5.4 AEROSOL MEASUREMENTS IN THE WORKPLACE

Aerosol sampling (i.e. collecting samples from the workers) is not a highly complex task but it does require significant attention to detail to obtain reliable results, and the use of relatively high-cost equipment. It is probable that only H&S practitioners who serve in industries with continuous aerosol problems (mines, quarries, foundries, etc.) would need to be set up for this task. Consultant occupational hygiene services should be able to serve most other needs.

Four different aerosol measurements important to the H&S practitioner are discussed here. They involve the sampling and analysis of:

- inhalable dust
- respirable dust
- fibrous dust
- diesel particulate.

Different devices are used to sample each of these. Sampling with the wrong devices can lead to over- or underestimates of the risk, depending on the nature of the contaminant. This can lead to incorrect or costly control procedures or inadequate protection of workers.

Differences between inhalable and respirable dust sampling are outlined below, together with typical applications and sampling procedures. The laboratory analysis for a number of typical applications is described.

5.4.1 GENERAL APPROACH

The sampling of aerosols to estimate disease risk has taken centuries to understand properly and just as long to develop into a practical form. Workplace aerosol clouds have complex characteristics of particle sizes and compositions. Numerous different sampling procedures and extensive chemical analytical facilities may be necessary. However, if the H&S practitioner understands the basic principles of aerosol measurement then, with adequate equipment and training, some workplace monitoring for aerosols will be able to be performed.

For example, for dusts, the H&S practitioner will first need to determine:

- whether a dust should be assessed as a respirable or an inhalable dust
- whether the dust is an acute toxic dust
- whether it can produce long-term chronic dust disease.

Such information provides the basis for proper assessment and control. It will also allow the H&S practitioner to give specific guidance to the employer or a consultant engaged to undertake workplace dust monitoring. Not all dusty situations will require monitoring. If a good assessment is made from knowledge of the dust, it is possible to recommend control procedures of ventilation or personal protection without the need for dust monitoring.

5.4.2 DEVELOPMENT OF WORKPLACE AEROSOL MONITORING

Before the current methods of aerosol sampling are examined, it is worth looking at the development of dust sampling over the last 80 to 90 years. With the very earliest of dust sampling equipment, those interested in examining the dust conditions in a workplace, typically a mine or a tunnel, reasoned that the ill health arising from inhaling the dust was probably related in some way to the amount the worker breathed in. Dust disease in miners had been known since the days of King Solomon, but it didn't attract much compassionate concern in the days when mine workers were slaves and prisoners. In fact, it was only in about the 15th and 16th centuries, when there was an unacceptable toll among the silver miners in Europe (who were responsible for maintaining the coffers of the European kings) that some interest (though not much assistance) was taken in their respiratory health.

It was not until the early 1900s that methods of quantifying dust levels became available, and although they were crude, they were ingenious. Mines of the time were not places of great technological development—for example, ventilation methods included using a roaring fire over an upcast shaft to induce air movement. One of the earliest methods of quantifying mine dust involved pumping a large quantity of air through a tube containing sugar, dissolving the sugar out and weighing the trapped dust.

Such methods were not very sensitive and could collect only one sample per shift. In the United States in the 1920s, developments in industrial hygiene produced methods of trapping dust particles in a liquid impinger, and of impacting the dust onto a cold glass slide (by inertial or thermal force). These portable samplers allowed an inspector to take many samples per shift. Impingement samples were assessed by means of a microscope, giving rise to the term 'dust count', and these and similar methods were employed in Australia until as late as 1984 by the NSW Joint Coal Board, when they were replaced by gravimetric sampling methods.

Particle counting methods, while far more sensitive than the previous methods of weighing the dust, had numerous problems. Sensitivity is important because some inhaled dusts cause respiratory disease even at very low levels. But one of the fundamental problems found by medical researchers was that there was no relation between the number of dust particles inhaled and the disease which they caused. This was because the size-selecting characteristics of the human respiratory system were largely ignored.

Over the 25 years following the Second World War, the largest ever health study of a group of workers was undertaken in the British coal mining industry to establish the relationship between inhaled dust and dust disease. By examining the dusts deposited in the lungs of deceased miners, the British Medical Research Council was able to propose a size distribution of one of the fundamentally important parameters (i.e. 'respirable' dust). Instruments have since been devised to capture this particle size profile.

Current methods used for dust sampling take into account the size-selective nature of the human respiratory system, and measurements are expressed as the mass of dust, rather than the number of particles, entering different parts of the respiratory system.

5.5 TYPES OF DUST-SAMPLING DEVICES

Two different types of dust samplers are used in workplace airborne dust monitoring, namely, direct reading devices and filtration samplers. Both have advantages and disadvantages, but for most applications, the filtration types are recommended as the

Figure 5.3 DUSTTRAK® direct reading aerosol monitor

more versatile. Any H&S practitioner involved in workplace dust monitoring should seek the advice of an experienced hygienist before committing expenditure to any one type of instrument.

5.5.1 DIRECT READING DEVICES

Despite their apparent attractiveness, direct reading devices for dust monitoring are not commonly used. Quality instruments are expensive, while cheaper ones lack the ability to discriminate adequately between respirable and inhalable dusts. Calibration is a problem with instruments not fitted with primary separating elutriators (devices used to separate and classify particles by allowing them to settle under gravity in a moving airstream; see Section 5.6.3).

Various devices such as the DUSTTRAK® aerosol monitor (Figure 5.3) are used in some dusty industries. The DUSTTRAK® is a laser photometer which detects light scattered by the presence of dust particles. The instrument can be configured to detect particles from the lowest size detectable of 0.1 µm up to either 1, 2.5, 4 or 10 µm, and concentrations can be measured from 0.001 to 100 mg/m^3. The DUSTTRAK® provides a direct real-time readout as well as data-logged results which can identify peaks, means, averages and other aggregated data. Direct reading instruments are very useful in evaluating control procedures in the workplace. They are often neither sufficiently small nor robust to be used in personal dust sampling, however. Further, most optical instruments over-respond in locations where high moisture or smoke is present (e.g. sprays, water mist, etc.).

5.5.2 FILTRATION SAMPLING INSTRUMENTS

The majority of dust sampling devices are of the filtration type. Advantages include relatively low cost, robustness, versatility in being able to sample different airborne dusts (e.g. wood, quartz, coal, metals, grains, organic dusts, powders, etc.).

The usual dust sampling equipment contains the following five elements, as seen in Figure 5.4:

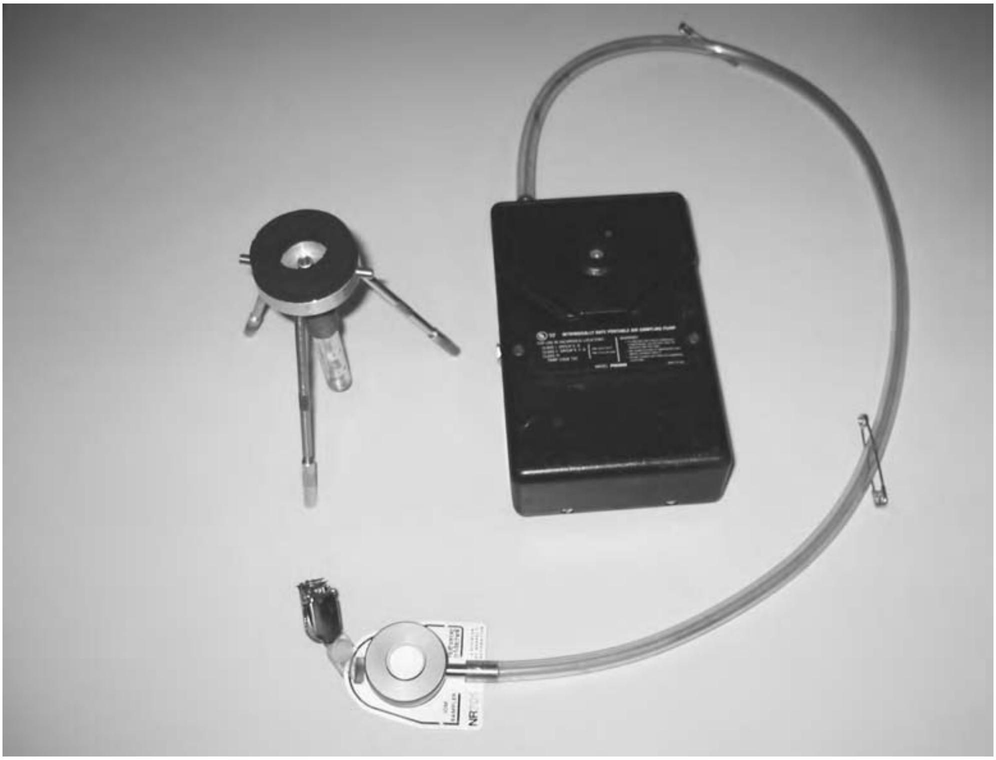


Figure 5.4 Typical personal dust monitor showing pump, sampling head and flowmeter

- filter
- filter holder incorporating a size-selective device
- suction pump
- connecting tubing
- flowmeter—not worn, but shown for sake of completeness.

In the absence of a belt, a harness can be used to conveniently attach the sampling equipment to the person using it.

Collecting dust on a filter and measuring its concentration occurs via the following steps:

- a known volume of dust-laden air is drawn by the sampling pump
- a size-selection device (first stage) may be used to reject some of the larger dust particles
- the finer particles of interest are collected on the filter (second stage)
- the collected dust is weighed on a microbalance or analysed by special techniques in a laboratory.

5.5.2.1 Filters

There are many different kinds of filters useful for workplace dust monitoring. Filters are chosen depending on the dust being sampled, the analysis to be carried out, and the environment being sampled. Some filters have grids, some have acid resistance, and some are transparent in certain light wavelengths. Filters may be made from polyvinyl chloride (PVC), polycarbonate, glass fibres, polytetrafluoroethylene (PTFE), mixed cellulose esters, etcetera, and have a range of different pore sizes ranging from 0.3 to 5 µm. Specialist advice on appropriate filter type and pore size should be sought for any new sampling task.

5.5.2.2 Sampling pumps

There are a number of sampling pumps which are useful for workplace aerosol monitoring. Some operate from mains power, but most nowadays are small, convenient, battery-powered pumps which can be worn by the worker. These pumps are designed to provide flowrates of between 0.5 and 5 litres per minute (L/min); most dust sampling is carried out between 1 and 2.5 L/min.

Good dust-sampling pumps have four important features:

- they are controlled so that the volume of air is accurately measured
- they are pulsation damped so that any size-selective device connected may operate correctly
- they have the ability to set flowrates over a wide flow range
- they have the capacity to operate at a reasonable pressure (e.g. up to 10 kPa).

Two other features important in choosing a sampling pump are continuous operating time and intrinsic safety. A fully charged pump in good operating condition should be able to operate for at least 8 hours. Intrinsic safety (i.e. able to be operated safely in explosive atmospheres) is mandatory for pumps used in workplaces where risk of explosion may be high (e.g. coal mines and petroleum refineries).

Most of the flowmeters built into sampling pumps suffer a serious design problem and should not be relied upon because they can indicate incorrect and variable flowrates. Any flowmeter used to measure the flowrate of a pump must be calibrated with a primary flowmeter: this is a flowmeter whose key properties are traceable to national measurement standards of length, mass and/or time. One example of a primary flowmeter is the ‘soap film flowmeter’, used in a calibration train similar to that in Figure 5.5. The soap film flowmeter uses the principle of timing the movement of a soap bubble along a transparent tube of known volume as a result of airflow produced by a pump.

5.5.2.3 Connecting tube and harness

The connecting tube used to connect the pump to the filter holder needs to be of high quality PVC (such as Tygon) or polyethylene that does not readily crush, retains its elasticity and does not adsorb dust onto its surfaces.

A stout belt or harness will be needed to suspend the pump. Pumps are generally too large to be carried in a pocket and they may be prone to accidental blockage if carried inside clothing. If a worker wears no shirt, a belt with a bandolier may be required to suspend the dust sampling device in the worker’s breathing zone.

Figure 5.5 Flowrate calibration train

5.6 SIZE-SELECTIVE SAMPLING DEVICES

There are several commercially available size-selecting dust samplers for particulate sampling. It is important that the correct one be selected for each sampling task. Details of the recommended samplers are given on the following pages. Only samplers with the correct performance can be used to make measurements which are in accordance with the exposure standards (ES).

While most sampling involves dusts, similar principles underpin sampling for mists.

5.6.1 INHALABLE DUST SAMPLING

Dust hazards will mostly be assessed on the basis of dust which a worker can inhale from the workplace air. This is commonly known as inhalable dust, and is similar to, but does not produce the same results as, 'total dust'. (The total dust sampler was developed in North America, and is not used in Australia or Europe.) Many particles in a visible dust cloud are aerodynamically too heavy to be captured by the respiratory system, which means that only a fraction of them are inhaled. It is important to remember that these inhalable dusts represent a wide size range and include a proportion of respirable particles. (Respirable dust is discussed in Section 5.6.2.)

Some of these inhalable dusts cause their effects at the site of deposition in the upper airways; they include:

- wood dusts causing nasal cancer (oak, beech, birch, mahogany)
- cement dusts causing airway irritation
- sensitising wood dusts causing asthma (e.g. western red cedar)
- proteolytic enzymes which attack cell structure

- tobacco smoke associated with lung cancer and a range of other respiratory diseases (nicotine measurement is often used as an indicator or marker of tobacco smoke).

Inhalable mists can contain oil, acids or alkalis, which require special analysis needing expert advice.

For sampling airborne cotton dust there is specific and highly specialised equipment known as a vertical elutriator, which allows only those particles of interest to be collected on a filter for gravimetric analysis. Only 'static' (i.e. fixed location samples) can be collected with this sampler because of its size. An inhalable dust sampler has been suggested but not adopted as an alternative (Institute of Occupational Medicine, IOM), but significant differences in dust concentrations can result from the use of such a device.

There is no universally accepted size criterion for inhalable dusts, because inhalability varies with the density of the dust. It may also depend on a number of workplace and human factors, such as wind speed, and whether the worker is a nose- or mouth-breather. For practical purposes, inhalable dust is defined as the fraction of a dust cloud collected by certain types of dust samplers. Australian Standard® AS 3640 (Standards Australia 2004c) provides definitions for two different samplers, now based on the common standard defined by the European International Standards Organization (ISO) criteria (1995), published as ISO 7708, harmonised with the definition used by the American Conference of Governmental Industrial Hygienists (ACGIH® 2005). The ISO criteria is seen in Figure 5.6, which shows that the collection efficiency of any inhalable sampler is above 90 per cent for particle sizes below 4 µm in diameter, and then drops to around 50 per cent efficiency for particles greater than 50 µm. In other words, not all particles are caught by the sampler, similar to the action of the human nose and mouth.

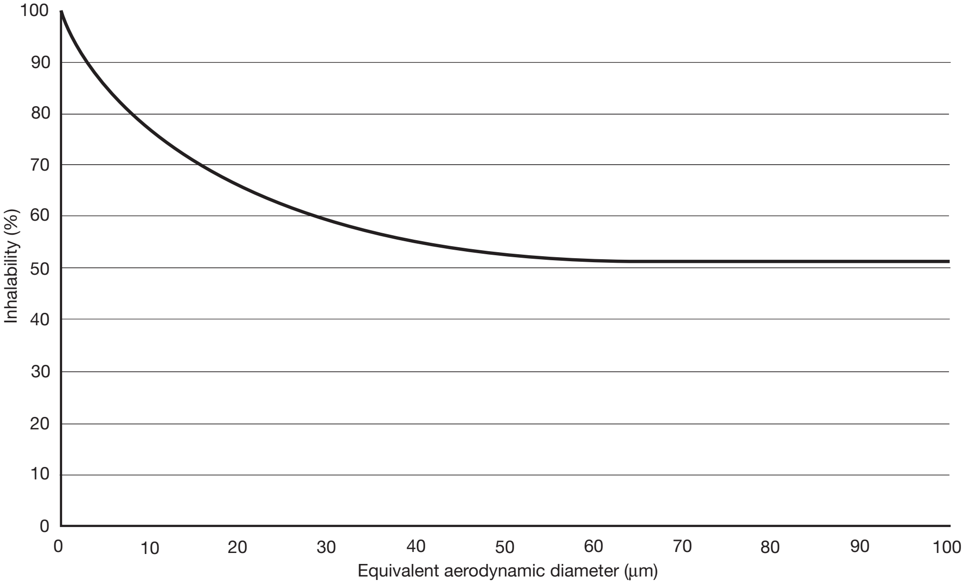


Figure 5.6 Inhalable dust sampler performance

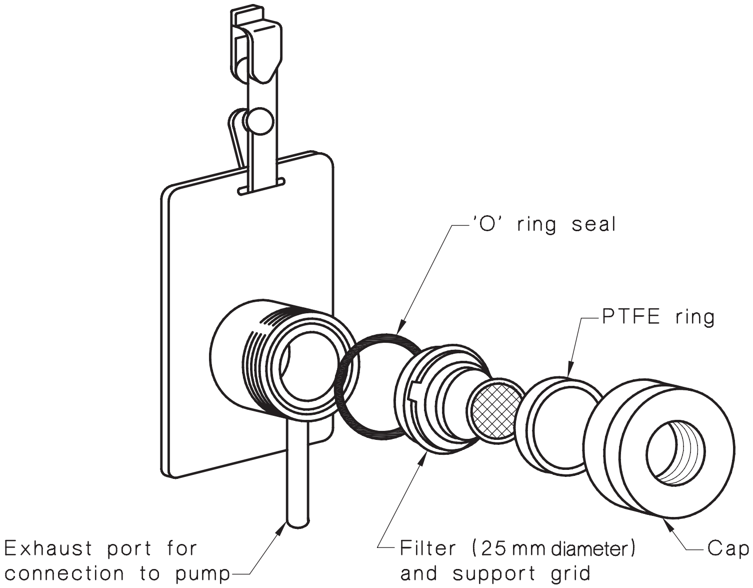


Figure 5.7a Exploded view of IOM inhalable dust sampler

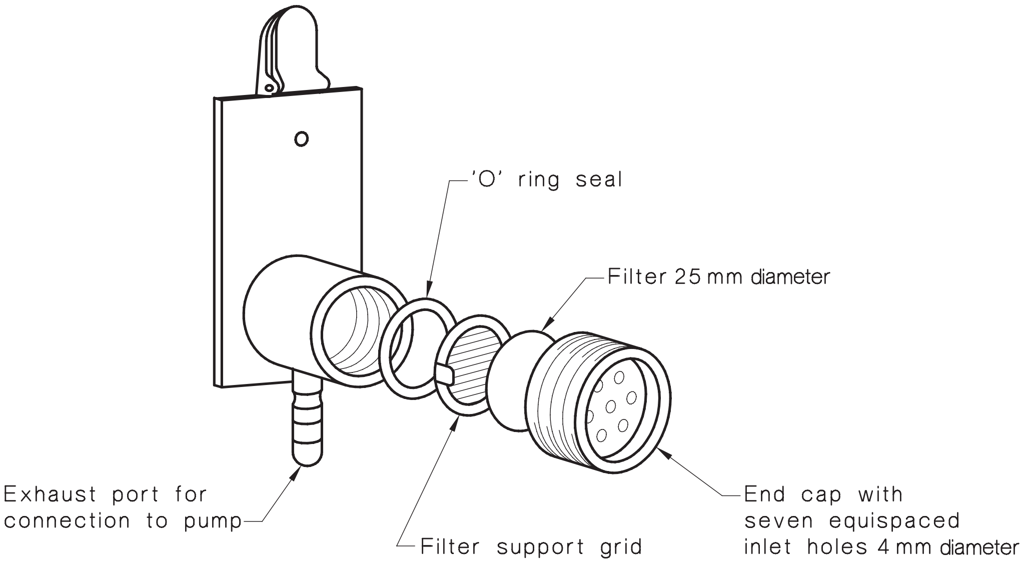


Figure 5.7b Exploded view of UKAEA 7-hole inhalable dust sampler

Two inhalable dust samplers are recommended by AS 3640 for use in conjunction with the exposure standards. Figure 5.7a shows the IOM dust sampler, which has been designed to overcome problems of different wind speeds past the wearer and sampler orientation (i.e. sampler facing horizontal or downwards).

Figure 5.7b shows the traditional modified United Kingdom Atomic Energy Association (UKAEA) 7-hole sampler. Use of the traditional open-faced sampler is normally avoided due to its propensity to over-sample in many situations involving large particle sized dusts. It is still useful when dealing with dusts which are known reliably to contain only small particle sizes (e.g. many thermally-generated metal fumes).

A detailed practical procedure for measuring inhalable dust in the workplace is given in AS 3640. The field sampling procedure specified in this standard can be conducted by H&S practitioners with appropriate sampling equipment and training. The laboratory follow-up requires some special equipment and techniques (e.g. microbalance, radioactive static eliminating sources, various analytical devices). This usually makes it necessary to use specialist laboratory services for the analysis.

On completion of sampling, the concentration in mg/m^3 of inhalable dust is calculated by dividing the net weight gain (after taking into account weight gain of a blank filter) by the total volume of air sampled.

Gravimetric weighing of the dust is not the only method of evaluating its concentration in the workplace. In fact, when there is a mixed dust, other types of laboratory analysis will be needed to determine the concentration of the contaminant of interest.

Examples would include:

- measuring metal dust contaminants in the presence of smoke and other fumes
- measuring polycyclic aromatic hydrocarbons (PAHs) in a foundry dust
- measuring a benzene-soluble fraction in a coke oven emission.

5.6.2 DUST DISEASES AND THE CONCEPT OF RESPIRABILITY

A typical dust cloud in a mine, quarry or factory contains dust particles ranging in size from large particles of 100 μm diameter to as little as 0.1 μm. So far we have examined how to measure that part of a dust cloud which can be breathed in (inhalable dust).

The other fraction of the dust cloud which is important to workplace health is the respirable fraction. Its recognition, economic and health importance, and how it is now measured are part of a classic story solving the cause of the most prominent of all occupational diseases.

Historically, a number of dust diseases such as silicosis and coalworkers' pneumoconiosis (also known as 'dusty lung') have been known to occur in miners, quarry workers, tunnellers, stonemasons and others in dusty trades. Both crystalline silica (silicon dioxide, also known as alpha quartz or 'free silica') and coal dusts can cause pneumoconiosis, which results in a permanent alteration of the lung structure. Exposure to crystalline silica dust can lead to silicosis, a fibrosis of the lung. Crystalline silica in the lung initiates a reaction involving macrophages (scavenging cells) which die and calcify, forming nodules which grow to about 1 mm in diameter which can be identified by X-ray of the lung. These small nodules grow and coalesce as the disease progresses.

Figure 5.8a shows the radiograph of the lungs of a miner with no dust disease; Figure 5.8b shows a case of advanced silicosis. The normal air space of the lung shows up as the dark shadow.

Figure 5.8a Radiograph showing clear lung fields

Figure 5.8b Radiograph showing advanced silicosis

Silicosis may progress from a relatively benign stage with little impairment to lung function to a severe form if exposure continues, and can lead to permanent disability or death. In some heavily exposed cases, it is believed that the risk of lung cancer may be increased. Early diagnosis and cessation of further exposure is therefore very important. The parts of the lung affected by fibrosis have no oxygen transfer capacity.

The reason that crystalline silica promotes fibrogenic disease of the lung is not entirely clear, although it may be linked to the electronic structure of the surface of free silicon dioxide crystals. Silicon dioxide which is bound up in complex silicates (e.g. basalt, ilmenite) produces little or no lung fibrosis. Freshly mined quartz in which the crystal surface is contaminated by other minerals shows lower initial fibrogenicity than would be expected from the amount of quartz present. However, if the surface layers are dissolved away, the quartz demonstrates its usual toxicity.

To early researchers, these dust diseases were generally found to be slow to develop, and more prevalent among miners who had worked longer. Often, the dustier the mine or workplace, the more likely the chance of developing dust disease, but not always. Severity and progression of disease also appeared to be related to the material inhaled. Gold miners working through quartz seemed particularly susceptible, as were stonemasons hewing and working granite. For the exposed worker who developed disease, it became clear that the disease was centred in the lung itself, not in the airways leading to the lung. This meant that not all the dust which was breathed in was implicated in causing the dust disease. Also, it became clear that because dust disease often appeared many years after exposure ceased, some of the dust must have remained in the lung, that is, it wasn't cleared away.

From this evidence it was realised that a technique had to be developed which was capable of providing data on the dust concentration within the size range reaching the critical parts of the lung for toxic action. These are the non-ciliated regions (i.e. regions without hair-like structures which help to transport secretions) of the lungs. Obviously, the size fraction had to be the very small particles of a dust cloud (less than around 5–10 µm).

Through various animal experiments, lung autopsies on deceased miners, and theoretical calculations, it was found that of all the particles of a size range which might penetrate the tracheo-bronchial tree and deposit in the lung, only a percentage of them actually do so. In the tortuous journey to the alveolar region of the lung, only the very smallest of particles stay in the airstream. Successively larger particles impinge to an increasing extent on the airway walls and are deposited. Disease development was found to be related to the mass of a particular size range reaching the lung.

5.6.3 RESPIRABLE DUST SAMPLING

These considerations led to the adoption of a definition of 'respirable dust' by the British Medical Research Council (BMRC) as recommended at the Pneumoconiosis Conference held at Johannesburg in 1959. Respirable fraction, which applied to the pneumoconiosis-producing dusts, namely coal and some other minerals, was defined in terms of the free-falling speed (i.e. terminal velocity) of 'unit density particles' (i.e. particles with the same density as water). The small particles (less than 1 µm in diameter) all penetrate to the lung. At 5 µm, penetration is only 50 per cent, and particles larger in diameter than 7.1 µm have no penetration to the lung. (This is sometimes referred to as the 'Johannesburg curve'.)

The BMRC recommended that two important techniques be followed in measuring dust samples:

- the dust be measured by mass (or surface area)
- if any compositional analysis had to be undertaken on a dust cloud, it should be undertaken only on the respirable fraction.

From this research, conducted over many decades, two practical instruments for measuring respirable dust have been developed—the horizontal plate elutriator and the cyclone elutriator. Both are **two-stage devices** consisting of an aerodynamic separator (first stage) followed by a collection filter (second stage). The **horizontal plate elutriator**, available commercially as the MRE 113-A Dust Sampler, is a primary reference device. Due to the fact that it is quite heavy and has to remain horizontal for correct sampling, its use is restricted to fixed location sampling.

The commonly employed practical device meeting the respirable dust size-selection criterion is the **miniature cyclone elutriator**, a small, portable device well suited to personal sampling.

Originally, the Higgins and Dewell miniature cyclone was developed by the British Cast Iron Research Association and known as the BCIRA cyclone. It was soon followed by a lighter cyclone developed by the Safety in Mines Research Establishment as a personal dust sampler. This is known as the SIMPEDS cyclone. To achieve the BMRC size-selective sampling criteria, each of these devices was operated at a flowrate of 1.9 L/min.

Figure 5.9 shows the commercially available SIMPEDS cyclone sampler, with its filter cassette and sampling filter.

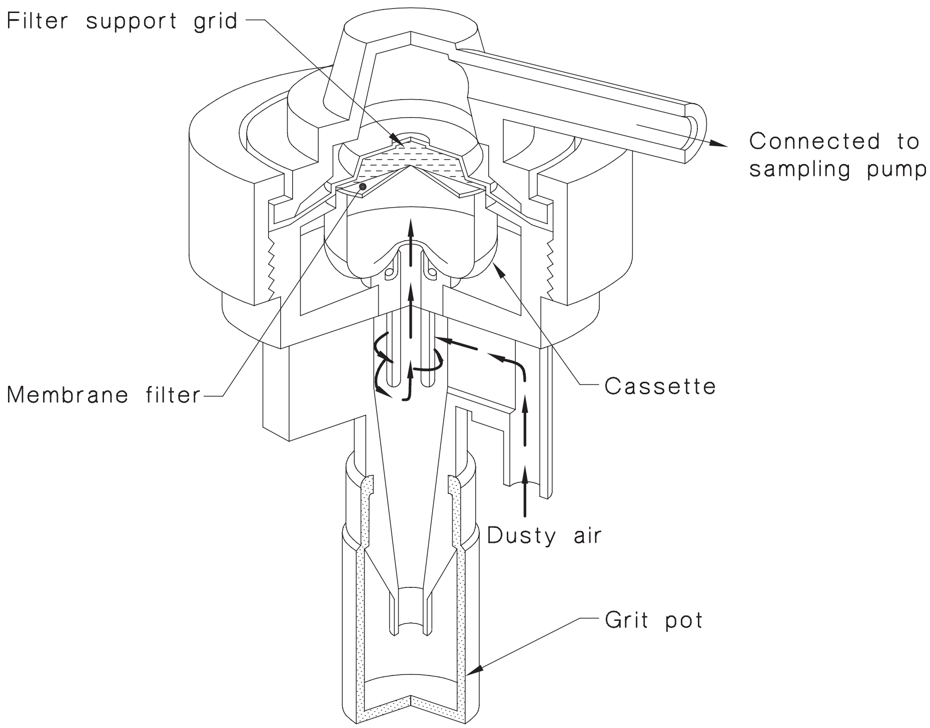


Figure 5.9 Exploded view of SIMPEDS cyclone sampler for respirable dust sampling

The 10-mm Dorr-Oliver aluminium cyclone, commonly used in North America, was designed to meet the ACGIH® sampling curve, which is different to the BMRC curve.

In 1995, the International Standards Organization technical report, ISO 7708 *Air Quality—Particle Size Fraction Definitions for Health-Related Sampling,* modified the BMRC respirable dust definition so that, for the first time, harmonisation could be achieved throughout the international community. This definition was adopted by the 2004 version of AS 2985 *Workplace Atmospheres—Method for Sampling and Gravimetric Determination of Respirable Dust* (Standards Australia 2004b). Respirable dust sampling in Europe, Australia and North America can now be conducted on a common basis, even when using sampling equipment originally designed to perform to different definitions of respirable fraction, provided that the flowrates in Table 5.1 are used.

Table 5.1 Flowrates for various cyclone size-selective samplers

Size-selective sampler	Flowrate (L/min)
BCIRA cyclone	2.2
SIMPEDS cyclone	2.2
10-mm Dorr-Oliver cyclone	2.5

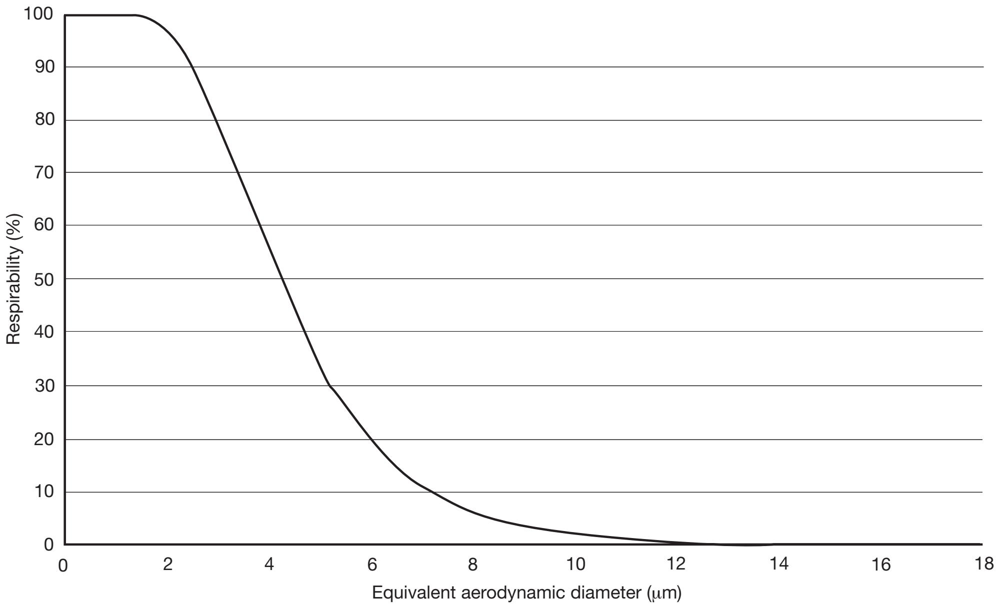


Figure 5.10 Respirable dust sampler performance

If operated at the correct flowrates, each of the above samplers operates at the ISO 7708 size-selective definition (ISO 1995), as seen in Figure 5.10. At these flowrates, the size-selective criteria are satisfied whereby unit density particles less than 2 μm in diameter are collected at greater than 97 per cent efficiency, 5 μm particles are collected at 34 per cent efficiency, and particles greater than 18 μm are not collected at all. As the specific gravity (density) of particles increases, smaller particles become aerodynamically equivalent to larger 'unit density' particles. For example, 5 μm unit density particles are equivalent to 3 μm quartz dust.

The H&S practitioner involved in respirable dust monitoring must ensure that sampling is conducted using appropriate equipment and with the correct flowrate. A detailed practical procedure for measuring respirable dust in the workplace is given in AS 2985 (Standards Australia 2004b). Monitoring procedures for respirable dust do not allow any latitude. Flow control is critical for correct size-selective performance. The field sampling procedure specified in this standard can be conducted by H&S practitioners who have appropriate sampling equipment and training.

The laboratory follow-up requires some special equipment and techniques (e.g. microbalance, radioactive static eliminating sources, various analytical devices). This usually makes it necessary to utilise specialist laboratory services for the analysis.

On completion of sampling, the concentration (mg/m^3) of respirable dust is calculated by dividing the net weight gain (after taking a blank filter weight gain into account) by the total volume of air sampled.

It is always strongly recommended that an H&S practitioner starting out on dust measurements should first contact an experienced occupational hygienist or a hygiene laboratory experienced in this field.

5.6.4 MATERIALS REQUIRING RESPIRABLE DUST MEASUREMENT

Most dusts producing pneumoconiosis are assessed by respirable dust monitoring. Table 5.2, though not exhaustive, contains those that are most important. Of these materials, quartz and coal dust are the most important in the workplace. The significance of coal dust arises because of the number of workers exposed.

Fibrous dusts (not to be confused with dusts which produce fibrosis of the lung) are examined in Sections 5.8 and 5.9.

Table 5.2 Various pneumoconiosis-producing dusts

Respirable crystalline silica:
  - alpha quartz
  - cristobalite
  - tridymite

Tripoli

Fused silica

Fumed silica

Microcrystalline silica

Coal dust

Graphite (natural)

5.6.5 SILICA DUSTS

In geological terms, the element silicon is the most abundant element on our planet, and a number of geological silicates are toxic to humans. The principal hazard arises from alpha quartz. It is the most commonly occurring of five different polymorphs of silicon dioxide, which all have the chemical formula SiO_2. Alpha quartz in its original state is fibrogenic to the lung, and may be transformed by heat to two of its other forms, cristobalite and tridymite, both of which are also fibrogenic.

The following examples are drawn from typical workplaces in which respirable dust exposures are important and in which H&S practitioners may need to undertake respirable dust measurement or respirable crystalline silica measurements.

5.6.5.1 Abrasive blasting

Abrasive blasting on large steel structural components, processing plants and exposed aggregate concrete products produces extremely hazardous concentrations of respirable dust. Most abrasive blasting regulations forbid the use of crystalline silica for dry abrasive blasting. All river and common beach sands are excluded from use. Only a few abrasives meet this stringent standard, namely ilmenite, copper slag, aluminium oxide and some other specially selected rock and mineral sands.

5.6.5.2 Concrete and masonry chasing

Building trades will be familiar with this process, in which concrete or masonry is cut to allow the laying of services such as electrical conduit into a wall, floor or ceiling.

Without good dust suppression and/or control, very high concentrations of both respirable dust and respirable quartz (up to 50 times the ES) may be generated. This can also be the case for mechanical removal of brickwork grout.

5.6.5.3 Pottery and brick-making industries

These traditional industries handling clay dusts which contain up to 20 per cent quartz have produced many cases of dust disease. A secondary hazard exists because some of the quartz can be converted to cristobalite in the furnace. Studios and pottery teaching colleges also produce respirable dusts, but on a much smaller scale than occurs in industrial processes.

5.6.5.4 Foundry industry

Foundry moulds are traditionally made from sand and various binders. Exposure to quartz occurs with moulders, and with the fettlers cleaning down the poured castings. Shot-blasting and working in sand reclaim (i.e. where sand is recycled from moulds already used) are also hazardous. The use of sand for these purposes is now banned in several states.

5.6.5.5 Beverage production

A common material used in filtering and clarification of beverages is diatomaceous earth. In its calcined (roasted) form, the material may contain 40–50 per cent cristobalite. Dusts from this material pose a potential hazard unless well controlled.

5.6.5.6 Sugarcane farming

There is a rare occurrence of biogenic silica (i.e. silica formed by the action of biological organisms) in sugarcane, to which workers can be exposed during harvesting. Exposure has lead to nasopharyngeal and broncho-pulmonary symptoms.

5.6.5.7 Stone masonry

Although not as common nowadays, some traditional sculptors and craftspersons can be exposed to quartz from working with sandstone and granite. The use of newer mechanical tools (chipping hammer and air bottle), which creates more dust from grinding and sanding than occurred with traditional hand methods, can lead to greatly increased risks unless properly controlled.

5.6.5.8 Quarrying and mining

Many building material quarries and road base quarries produce respirable dusts containing free silica in their cracking and crushing plants.

5.6.5.9 Coal dust

Coal dust has a very important place in the history of understanding dust diseases, their development and their progression. Studies in coal mines contributed greatly to the development of dust-sampling technology. However, for the H&S practitioner, there will be only a few above-ground workplaces where coal dust can still be found. Even in mining, the hazard from inhalation of coal dust, in Australia particularly, has diminished dramatically. The excellent record now achieved is testimony to the decades of research and improvement which have produced acceptable working conditions for miners. But it was not always so. Coal mining is a very important example to reflect upon, in judging the value and worth of occupational hygiene in the workplace.

Coal mining in Australia, and worldwide, had been plagued with dust diseases right up until the end of the Second World War. As many as 50 per cent of miners developed some form of disabling respiratory disease or suffered premature death. The cost in human suffering and loss of productivity was staggering. This occurred at times when coal mining was a key industry in the industrialised nations. In this industry above all others, occupational hygiene research and the resulting control strategies in the work environment have demonstrated one of the most dramatic reversals in the economic prosperity of an industry, together with large benefits which have flowed from having a healthy workforce.

The dust disease suffered by coal miners is known simply as coalworkers' pneumoconiosis (CWP). It is caused by the inhalation of coal dust, with a probable implication of inhaled quartz as well. In its simpler form, CWP will usually be asymptomatic, even though detectable in lung X-ray. It can progress following further exposure to show extensive but discrete lesions on the X-ray. Advanced simple CWP is important because it may lead to the most severe form, progressive massive fibrosis (PMF). In PMF, the lesions coalesce to show extensive large opacities on the X-ray. The lung in these areas becomes a hard black mass, severely reducing breathing capacity, which leads to disability and perhaps premature death.

In the Australian coal mining industry, the cases of CWP still existing have arisen largely from exposures some decades ago, and PMF is nonexistent in the industry. Coal related dust disease of this classic kind occurs only in the underground mining population; open-cut mining produces no significant exposure to coal dust.

The relentless application of better ventilation in response to more stringent respirable dust standards has resulted in this fall in incidence of CWP and PMF in coal miners.

Apart from underground mining, the H&S practitioner will still find coal dust associated with coal-fired furnaces, train loading stations and unloading ports, and in a few laboratory facilities which crush coal in preparation for analysis.

5.6.6 LABORATORY ANALYSIS OF RESPIRABLE QUARTZ

Most particulate samples obtained by air sampling will contain a mixture of materials and thus will probably require laboratory analysis to determine composition.

In practice, laboratory analysis for quartz is conducted on most respirable dust samples. Quartz analysis is conducted by a few specialist laboratories accredited by the National Association of Testing Authorities (NATA) using one of two National Health and Medical Research Council (NHMRC) methods adopted and published unchanged by NOHSC (NHMRC 1984): infrared spectrometry and X-ray diffractometry.

Infrared spectrometry is appropriate for most samples; however, if cristobalite may be present in any quantity (i.e. if the quartz has undergone heat treatment above 450°C), then X-ray analysis will be necessary. Fourier transform infrared spectrometry (FTIR) has proven to have detection limits and selectivity equal to or better than X-ray diffraction, and is reasonably free of interference if proper care is taken during the analysis.

Figure 5.11 shows the infrared spectrum, or 'fingerprint', of quartz. The concentration of respirable quartz can be determined directly from the spectral intensity of the double peak at 798 and 779 cm^{-1} wavenumbers.

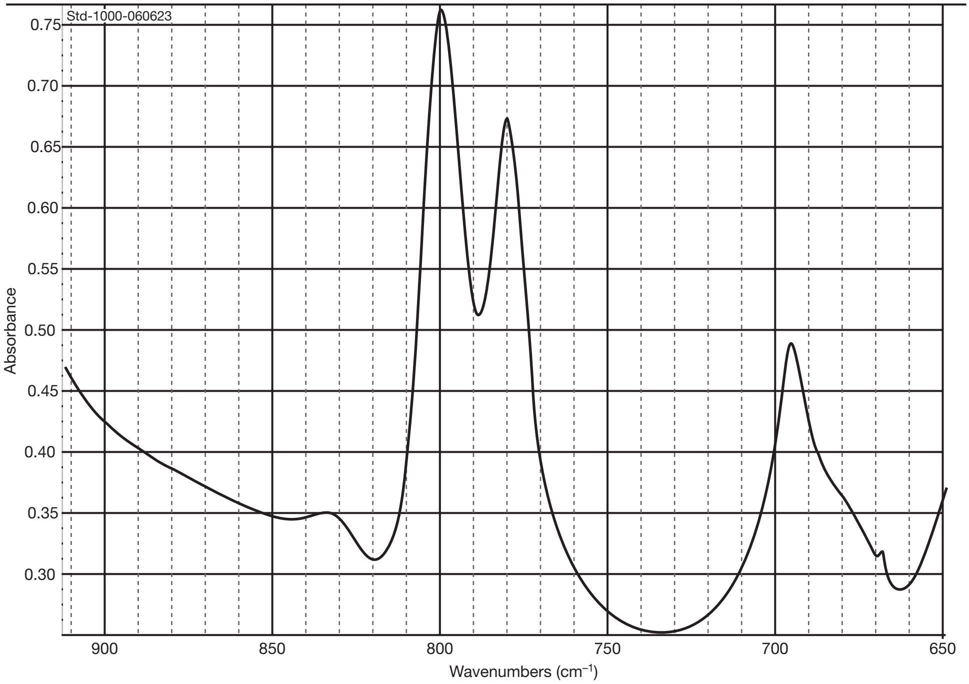


Figure 5.11 Peak heights are measured of spectral doublet for determination of respirable quartz by infrared spectrophotometry

5.7 DIESEL PARTICULATE

Diesel particulate is one of the particulate aerosols which have been the subject of considerable research in the past 15 to 20 years. As productivity requirements within industry have resulted in the use of larger and more powerful diesel engines, there has been a similar increase in the potential for adverse health outcomes due to the larger number of workers exposed to diesel exhaust emissions. Diesel emissions are made up of both gaseous and particulate fractions with the health effects of the gaseous fraction being recognised for decades. However, it is only in the past 20 years that diesel particulate has been recognised as a health issue. As a result, statutory authorities throughout the world have begun to impose occupational and environmental limits on the amount of diesel particulate that diesel engines produce, and in some jurisdictions to introduce workplace and environmental exposure limits.

5.7.1 COMPOSITION OF DIESEL PARTICULATE

Amman and Siegla (1982) summarised the early research on the composition of diesel particulate and defined diesel particulate as 'consisting principally of combustion generated carbonaceous soot with which some unburned hydrocarbons have become associated'. Using photomicrographs of the exhaust from a diesel passenger car, they demonstrated that diesel particulates were made up of a collection of spherical primary particles termed 'spherules' which formed aggregates resembling in appearance a range of forms from a cluster of grapes to a chain of beads. Subsequent researchers have confirmed that the spherules (as nanoparticles) vary in diameter from 10 to 80 nanometres (nm), with most in the 15–30 nm range (there are 1000 nanometres in one micrometre).

High resolution electron microscopy (Figure 5.12a) indicated that the basic spherule consisted of an irregular stacked graphitic structure, so-called elemental carbon, shown schematically in Figure 5.12b (Rogers & Whelan 1996; WHO 1996).

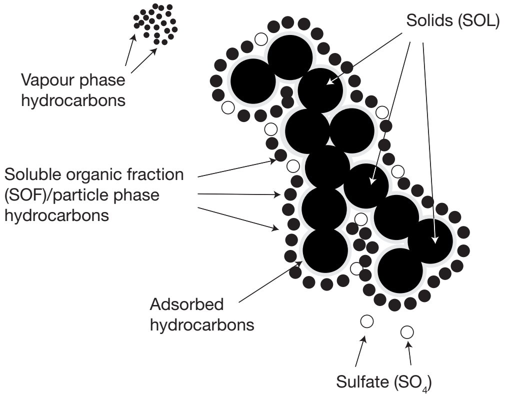


Figure 5.12a Electron micrograph—mine diesel particulate showing spherules, chains and agglomerates (Rogers & Whelan 1996)

Figure 5.12b Schematic—mine diesel particulate showing spherules, chains and agglomerates

The graphitic nature and high surface area of these very fine particles (typically <1 µm in diameter) means they have the ability to absorb significant quantities of hydrocarbons (the organic carbon fraction) originating from the unburnt fuel, lubricating oils and the compounds formed in complex chemical reaction during the combustion cycle. Traces of inorganic compounds have also been found in the particulates (e.g. sulphur, zinc, phosphorus, calcium, iron, silicon and chromium). These are believed to have arisen from the fuel and additives to the lubricating oil used in diesel engines.

5.7.2 HEALTH EFFECTS

The potential for adverse health effects arising from occupational exposure to diesel particulate has been the subject of intense scientific debate for the past 25 years. A detailed review of this research is provided in the Australian Institute of Occupational Hygienists' publication, *A Guideline for the Evaluation and Control of Diesel Particulate in the Occupational Environment* (AIOH 2004). This document should be consulted if detailed information on the health effects of diesel particulate is required. However, the following general statements on adverse health effects can be made:

- Diesel particulate has the potential to irritate the mucous membranes of the eyes and respiratory system.
- The available evidence suggests that long-term exposure to diesel particulate may result in an increased risk of lung cancer compared with unexposed workers. However, the level of increased risk is subject to intense debate due to the lack of reliable exposure data.

5.7.3 EXPOSURE STANDARDS

The development of workplace exposure standards for diesel particulate is still in a state of flux. This is a result of the paucity of dose–response risk data, different approaches to sample collection and analysis methodology, and different approaches being taken by various industry segments, advisory groups and regulatory authorities.

While international regulatory authorities struggle with this issue, research within the Australian mining industry has found that if atmospheric levels of diesel particulate are reduced below 0.2 mg/m^3 diesel particulate (DP), or approximately 0.1 mg/m^3 elemental carbon, the level of eye and upper respiratory tract irritation is significantly reduced. This outcome has evolved from observations made over a number of years while collecting in excess of 1000 personal samples across a wide range of mines and mining operations (Pratt et al. 1997; Rogers & Davies 2001). On this basis the NSW Minerals Council (1999) has proposed an industry best practice exposure standard of 0.2 mg/m^3 (as submicrometre DP, equivalent to 0.16 mg/m^3 submicrometre total carbon, or 0.1 mg/m^3 submicrometre elemental carbon). The Minerals Council acknowledges that although compliance with such a standard would offer substantial improvement for workers' comfort, there is insufficient evidence to suggest such a standard would prevent the development of diseases such as cancer. The Minerals Council publication goes on to suggest that worker exposure levels to diesel particulate should be reduced as low as reasonably practicable through effective control strategies.

In summary, the promulgation of a dose–response workplace exposure standard linked to sound epidemiological or dose–response evidence does not appear likely within the near future. There is strong evidence to indicate that reducing workplace exposures to below 0.2 mg/m^3 submicrometre DP (or 0.1 mg/m^3 submicrometre elemental carbon) will significantly reduce irritation effects. In situations where this standard has been introduced and achieved, the number of employee complaints has dropped (or in many cases ceased) and productivity gains have been observed.

The effectiveness of such a standard in reducing the potential risk of cancer is unknown, due to the uncertainties surrounding published epidemiological studies.

5.7.4 MONITORING METHODS

Methods for monitoring diesel particulate in the workplace have been in a process of transition for a number of years, mainly due to the shift in focus from particulate mass (gravimetric) to elemental carbon concentration (thermal analysis).

The monitoring method which has achieved widespread international acceptance is NIOSH Method 5040 (NIOSH 1999). In this method the diesel particulate is collected on a quartz filter inside a cassette incorporating precision sapphire nozzles and an oiled impactor. These collection units are single-use disposable cassettes manufactured in the United States.

Specific details on sample collection and analysis methods such as NIOSH Method 5040 can be sourced from the AIOH Guideline on Diesel Particulate (AIOH 2004).

5.7.5 CONTROL TECHNOLOGIES

The development of effective control technologies for diesel particulate has also been evolving as greater understanding of its characteristics has become available. Regulatory authorities in both the United States and Europe have reacted to the increasing knowledge base by requiring engine manufacturers to produce cleaner engines and to introduce them to the market as problems are overcome or new designs become available.

While this approach will result in a dramatic reduction in diesel emission levels in the future, many older diesel engines remain in service and will do so for some time to come. The control of emissions from these engines presents unique challenges, but experience has shown that while no single simple solution to control particulate levels exists, a range of options in one or more configurations can be effective. These options include the use of:

- low emission diesel fuel
- ventilation at levels commensurate with the size of the engine. In cases where ventilation is restricted (e.g. mines) it may be appropriate to limit the number of diesel engines operating in an area
- exhaust treatment devices such as catalytic converters, wet scrubber systems, regenerative ceramic filters, disposable exhaust filters, exhaust dilution–dispersal systems
- new generation low emission engines
- maintenance programs targeted at minimising exhaust emissions
- well-sealed and filtered air-conditioned operators' cabins
- personal protective equipment. Care should be exercised when selecting respiratory protective equipment as little data exists on the effectiveness of such devices

against elemental carbon. In all situations other control technologies should be explored in preference to personal protective equipment.

Although the range of options listed here currently exists, each situation needs to be evaluated on its merits and a resultant management plan developed. In some cases this may be as simple as redirecting an exhaust away from personnel and in others it may be the retrofit of one or more sophisticated control technologies.

5.8 FIBROUS DUSTS—ASBESTOS

Of all the hazards the H&S practitioner will have to deal with, asbestos in the workplace will probably have the highest profile and often involve much debate, emotion and worker concern. Asbestos has been one of the most widely evaluated substances with tens of thousands of published books, articles or research reports available. While the history of the 'unquenchable' fibre, used since antiquity in lamps, pottery and woven garments, has been illuminating, its relatively recent past has highlighted its less fortunate legacy. There are fascinating stories, such as Charlemagne throwing an asbestos tablecloth into the fire and retrieving it before the eyes of astonished guests, or the Canadian cowboy recovering his hand-woven asbestos socks from a fire only to be accused of possessing occult powers. Sadly, these have been overshadowed by the grim harvest of occupationally-related deaths caused by the inhalation of the fine fibres of asbestos. A century of commercial mining and use of the fibre in manufacture has often been under conditions which could be described only as terrible.

5.8.1 PUBLIC CONCERN ABOUT ASBESTOS

Most of the recent concern has arisen since asbestos has been shown to be a human carcinogen, and asbestos has been singled out for public paranoia or, seemingly more appropriate, banning. Arguments on the assessment of the real risks have been sometimes clouded by emotion.

5.8.1.1 What is asbestos? What makes it dangerous to health?

For the H&S practitioner who is interested in health rather than geology, the term asbestos is limited to the commercially used fibrous minerals of one serpentine rock and the amphibole series. The fibrous forms of these minerals have flexibility, good tensile strength and some are able to be woven. They show good resistance to heat, they are non-conductive and the amphiboles especially show good acid resistance. Many other minerals in fibrous form (e.g. wollastonite, fibrous brucite) occur, but they are not asbestos. Fibrous minerals have also occasionally been identified in some mineral deposits worked for their metals (e.g. nickel, iron ore).

5.8.2 SOURCES AND TYPES OF ASBESTOS

Many years ago, mining of asbestos was conducted in Australia, particularly in New South Wales and Western Australia. Asbestos continues to be mined and/or extensively used in many other countries because of its useful properties. Unlike Australia, these countries still have significant numbers of workers involved in the manufacture of asbestos-containing products.

The commercial types of asbestos which are commonly found in workplaces are:

- chrysotile, belonging to the serpentinite family (also commonly known as 'white' asbestos)
- the amphiboles, including:
  - amosite, commonly known as 'brown' asbestos
  - crocidolite, commonly known as 'blue' asbestos
  - actinolite asbestos (uncommon)
  - tremolite asbestos (uncommon)
  - anthophyllite asbestos (uncommon).

It is useful to have knowledge of the different types of asbestos fibre in order to understand the different diseases they can cause and the risks associated with each fibre type in the workplace.

5.8.3 HEALTH EFFECTS OF ASBESTOS

Like crystalline silica and coal, exposure to asbestos causes diseases directly in the respiratory system. Where asbestos is present in a workplace process (e.g. grinding an asbestos-containing brake shoe), airborne asbestos fibres are generated. The hazard in the workplace arises if these fibres are inhaled.

Today, asbestos may be present in the workplace as a product, as an insulant or as part of the fabric of a building. Thousands of workplaces have many hazardous materials in them—the risk materialises only when workers are exposed to the hazard. The risks associated with asbestos depend entirely on fibres becoming airborne. Occupationally, the diseases it causes are primarily respiratory diseases, related to fibres of respirable size. Occupational disease is not related to skin contact, but ingestion is suspected to cause disease in a few sites (liver, prostate) where heavy ingestions have been recorded.

Fibres of respirable size are those which are smaller than 3 µm in diameter, usually longer than 5 µm and have aspect ratios of at least 3:1 length to width.

The three major occupational lung diseases of interest caused by asbestos are:

- asbestosis
- lung cancer
- mesothelioma.

Not all the different types of asbestos listed above have strong associations with these diseases. In Section 5.8.6, the risk factors and the likelihood of any of these diseases occurring from present occupational exposure to asbestos are examined.

5.8.3.1 Asbestosis

Pulmonary and pleural asbestosis is found only in asbestos workers who have been exposed to high fibre concentrations over a long period of time. It is the classical disease of the asbestos miners, millers, weavers and those involved in processing fibre in large quantities (e.g. manufacturing brake linings or asbestos cement products). White asbestos (chrysotile) and the amphiboles (amosite and crocidolite) have all caused asbestosis. In pulmonary asbestosis, the inhaled fibres penetrate to the alveolar region of the lung where a fibrotic reaction takes place. There are no well-defined nodules as seen in silicosis. Pleural asbestosis, also known as pleural plaques, presents in the form of calcification of the outer and generally top surface of the lung. It does not in itself progress to pulmonary asbestosis and is usually not debilitating.

Mild cases of pulmonary asbestosis are usually symptomless, but may progress, particularly with further exposure, to increasing breathlessness. Onset of asbestosis typically occurs only after 15 to 40 years' exposure to airborne fibres. With increasing shortness of breath following fibrosis of the lung, the oxygen exchange capacity can decrease drastically, leading to associated heart failure.

5.8.3.2 Lung cancer

Historically, an increased incidence of lung cancer was observed among workers heavily exposed to any type of asbestos, and a greatly increased risk of lung cancer occurred when heavily exposed asbestos workers were also heavy smokers.

Recent research has shown that when cigarette smokers have had a small exposure to airborne asbestos fibres, their lung cancer is completely or almost completely caused by smoking. Only very small numbers of non-smoking asbestos workers not showing signs of asbestosis have died from lung cancer. Latency periods are around 20 years or more, and quitting smoking eventually reduces the risk in time.

5.8.3.3 Mesothelioma

Mesothelioma is a rare disease, occurring most often among those exposed to asbestos but also quite rarely in some unexposed people. Its latency period is usually 30 to 40 years and typically follows exposures which are substantial, but in some cases thought to have been caused by brief but intense exposures of a few months or less. Adults are reported to have developed the disease in their late twenties after being exposed as young children from dust carried home on a parent's clothing.

On the other hand, some 2 to 4 cases of mesothelioma per million people per year occur with no known exposure to asbestos. Recent evidence shows that there is a strong genetic factor supporting high prevalence of mesothelioma among a particular group of non-exposed individuals.

It is well established that crocidolite (blue asbestos) exposure causes this malignancy, with some cases also attributable to amosite (brown asbestos), and with exposure to mixtures of these fibres with chrysotile (white asbestos). There is a weak association (some orders of magnitude lower than that of crocidolite) between chrysotile asbestos exposure and mesothelioma.

The crocidolite exposure of miners, mill staff and others at Wittenoom in Western Australia has established the propensity of this fibre to cause mesothelioma.

Wittenoom crocidolite is documented to be one of the dustiest of the crocidolites, compared with those from South Africa and Bolivia, and it was widely distributed throughout Australia in the 1950s and 1960s.

The greatest risk of mesothelioma may be associated with the ability of an asbestos mineral or product to produce durable and long (>10 μm) fibres. The evidence of mesothelioma among asbestos workers exposed to chrysotile exposure alone is not as convincing. However, the extensive industrial use of chrysotile means that more cases of chrysotile-only related mesothelioma may appear during the next few decades.

Mesothelioma is a malignancy of the mesothelium cells of the pleura surrounding the lung (pleural mesothelioma) or abdomen (peritoneal mesothelioma). Radiologically, a mesothelioma is seen to present as large masses of tumour protruding into the lungs. The disease is invariably fatal, usually within 1 to 3 years of diagnosis.

5.8.4 OCCURRENCE OF ASBESTOS IN THE WORKPLACE

Any use of crocidolite or amosite in new applications in Australia was banned in the 1990s. It still exists in insulation in older buildings and equipment, and crocidolite can still be found in some asbestos cement materials manufactured prior to 1966. Industrial use of asbestos diminished rapidly during the 1980s throughout Australia. In the building materials industry, its use in the manufacture of asbestos-cement sheeting and piping was phased out completely by 1984. It is still encountered during maintenance, refurbishment and demolition activities.

Asbestos is most likely to still be found in Australian workplaces in:

- insulation on boilers and pipes in steam-raising plants. In this service, the asbestos can be as raw fibre lagging, or in a cementitious form combined with magnesite (magnesium silicate) as a trowelled plaster on steam pipes, calorifiers, outer furnace skins, etc. Some ships have been extensively fire- and heat-insulated with asbestos
- fire-retarding insulation on steel-framed supports in buildings, particularly high rise buildings
- fire stoppings in buildings between floors, tops of walls, cable risers
- decorative finishes and acoustic attenuation on ceilings and walls in auditoria, public halls, schools, hospitals
- space insulation in buildings, particularly beneath metal-sheeted roofs and in the ceiling spaces of homes and other buildings. It has also been used to prevent condensation in large buildings in the risers which carry air-conditioning ducts
- asbestos-cement building products in flat or corrugated sheet form and pipes for water reticulation
- friction brake and clutch products
- some gaskets and valve packing (chrysotile)
- millboard for air-conditioning heater banks
- asbestos fabric as fire-proof rope, gloves, mats and hoses
- older style vinyl flooring materials

- bituminous felt used on roofs and around oil and petrol pipelines
- asbestos-containing materials (mainly asbestos-cement) in soil as the result of demolition or dumping
- as a naturally occurring mineral in mines and quarries.

While processing was restricted to chrysotile asbestos prior to December 2003, there is now an Australia-wide prohibition of the use of any type of asbestos in new products, with only some exemptions allowed (e.g. mission critical components for the Australian Defence organisation and various applications for compressed asbestos fibre gaskets).

Although there seems to be a drive for an asbestos-free Australia, this will not be achievable except in the very long term. The durability for which asbestos has been prized means that it will still be present in walls, ceilings, floors, roofs, pipes, etcetera decades from now. There is no register for all the places it has been incorporated, nor the thousands of commercial or domestic items which contain it. For some purposes, substitutes are inferior. The ubiquitous use of asbestos-cement in domestic and commercial premises has caused a significant problem when previously used land that contains asbestos-cement contamination is redeveloped.

5.8.5 ASBESTOS EXPOSURES IN THE WORKPLACE

The current exposure standard for all forms of asbestos is 0.1 fibres per millilitre of air, averaged over a full work shift. Past industrial procedures involving handling of asbestos fibre on a large scale generated comparatively large risks compared with those occurring today. Manufacture of asbestos-cement building products often yielded fibre concentrations in the range of 1–10 fibres/mL or more in uncontrolled situations. Preparation of boiler re-insulation by hand mixing produced around 10–50 fibres/mL. The popular form of limpet or sprayed asbestos for fire insulation produced fibre concentrations of tens to hundreds of fibres/mL. Some individual operations involving cleaning of baghouse filters are believed to have produced fibre concentrations of hundreds to thousands of fibres/mL.

The largest use of asbestos in Australia was in the production of asbestos-cement building products. This has been superseded since the early 1980s by an asbestos-free cellulose technology in Australian manufactured products. A number of imported building products labelled as 'asbestos free' sometimes contain a small proportion of asbestos fibre (<5%). Exposure can still occur in the friction material industry, particularly in the re-manufacturing plants stripping and replacing brake linings. The following processes which generate fibre in the workplace air are the ones that may still be encountered, even though the presence of asbestos may not be known to the worker:

- grinding, drilling, sanding and sawing (using power tools) of building materials containing asbestos (2–50 fibres/mL), including high-pressure water blasting (up to 1 fibre/mL)

- blowing-down brake drums with compressed air during repair (up to 10 fibres/mL for several minutes)
- asbestos-stripping operations (up to 100 fibres/mL).

The last category, the asbestos removal industry, can be a source of potential exposure to asbestos fibre on a large scale. Asbestos removal programs are discussed in Sections 5.8.5.3 and 5.8.5.4.

5.8.5.1 Worker exposure today

Exposure of workers to asbestos occurs in three main ways:

- those who work in situations where asbestos materials have been deployed, primarily as insulation. For example, maintenance or service installers, working in ceiling spaces of buildings where sprayed asbestos is installed, may disturb the insulation and be exposed to the fibre. If asbestos is not disturbed, the exposure will be very low or nonexistent for building occupiers
- those who work with asbestos materials without protection, either not knowing or not caring that it is asbestos
- those building occupiers remaining near the site of an asbestos removal operation which is not well controlled—unlikely but possible, especially in regional or remote areas.

5.8.5.2 Asbestos in soil

The major asbestos 'problem' of today and the future (Pickford et al., 2004) is *not* the removal of asbestos insulation, but the treatment of land contaminated with asbestos-containing materials (ACM), of which the majority is asbestos-cement (AC). This material has come from illegal dumping, the inappropriate demolition of AC structures in the past, and inadequate remediation of contaminated land sites.

There is currently little guidance on remediation and validation of ACM-contaminated soils, and it is vital that risk management approaches be used in place of ad-hoc procedures.

Many public, environmental and government stakeholders have been unduly concerned that disease is linked with a casual and brief contact with a small amount of stable AC in soil. Together with substantial and often ill-informed press coverage, the sight of workers in suits and respirators performing trivial tasks associated with minor amounts of AC in good condition has created a public perception that these tasks are dangerous to workers and communities.

Further, there is a general expectation by some state regulatory authorities that buried asbestos (which includes AC) is required to be considered as friable asbestos material, and that an asbestos removal contractor with a licence for friable asbestos is required for its removal. It should be noted that the common definition of friable asbestos material is any material that contains asbestos and is in the form of a powder or that can be crumbled, pulverised or reduced to powder by hand pressure when dry. The current NOHSC publications on asbestos (NOHSC 2005a; 2005b; 2005c) are applicable to the removal of asbestos in structures (mainly friable asbestos insulation) but not to the removal of asbestos in soils, which means that inappropriate, variable and expensive procedures may be adopted by friable asbestos removal contractors.

There is a widespread perception that AC becomes friable when being processed by earth-moving equipment. However, direct observation by National Association of Testing Authorities (NATA) accredited laboratory analysts and occupational hygienists of many thousands of pieces of AC located on contaminated sites received for laboratory analysis show that while some pieces fracture, an insignificant number may become abraded, but essentially none become 'friable' in relation to the broad definition of friable used throughout Australia. Further, laboratory analysis of thousands of soil samples taken from AC-contaminated sites, often in the immediate vicinity of the AC itself, shows the absence of respirable asbestos fibres.

The emotive aspects of asbestos have lead to a 'zero' tolerance for the presence of asbestos, which is impossible to achieve scientifically or practically. Consequently, soil that is extensively contaminated with AC is removed to an approved waste management depot. Small amounts of AC contamination are often removed by hand, and the remaining soil is inspected and sometimes re-tested for the presence of asbestos before being certified satisfactory for the intended use. Other forms of remediation, including full-scale screening, are possible for a limited number of situations. All of these options are expensive, and the disposal of soil exhausts scarce landfill sites. It is therefore important for regulators to develop and adopt formal and practical guidelines for the management of asbestos-contaminated soil.

5.8.5.3 Asbestos removal

The asbestos removal industry has developed during the last 30 years, with special isolation and sealing requirements to prevent the spread of asbestos fibres during a removal procedure. The merits of premature removal part-way through the normal service life of in-situ asbestos-containing products are not examined here. In most cases, no health-related need has been identified for its removal, since fibre monitoring invariably has revealed counts of <0.01 fibre/mL. Sometimes employee demands, combined with sanctions on some business-related activity, have forced building owners to seek removal as a palliative measure. As a general rule, the planned removal of friable asbestos materials is a good principle and can avoid accidental exposure in the future. Generally, removal is necessary or prudent prior to building alterations or refurbishment.

When an asbestos-lagged installation requires maintenance, or where an insulating product fails in service, asbestos removal is generally appropriate or necessary. Examples of commonly failing products are sprayed decorative/acoustic surface finishes in which, as they age, adhesion fails and the materials can fall in large slabs. Water penetration or continuous external damage are also indicators of possible poor adhesion necessitating removal. Fire-rated structural beams which have lost some of their insulation must also be targeted for remediation, in which asbestos removal and reinstatement with an asbestos-free insulation is necessary. Where sprayed asbestos exists as insulation on the inside surfaces of air-conditioning systems, removal is a high priority.

When a building or structure is to be demolished or extensively refurbished, all asbestos present should be removed prior to these actions. For the H&S practitioner, the greatest priority is to ensure that the asbestos removal is conducted safely. Both the asbestos removal worker and the bystander require protection. Poor work practices in the lucrative asbestos insulation removal industry in commercial, high-rise and domestic dwellings in the 1980s and 1990s resulted in poorly conducted asbestos removals and remnants of asbestos insulation left in situ.

5.8.5.4 The NOHSC code and guides for asbestos removal and management

These nationally adopted documents providing the detailed guidelines are important for H&S practitioners:

- *Code of Practice for Management and Control of Asbestos in Workplaces* (NOHSC 2005a)
- *Code of Practice for the Safe Removal of Asbestos* (NOHSC 2005b)
- *Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres* (NOHSC 2005c).

Code of Practice for Management and Control of Asbestos in Workplaces (NOHSC 2005a) applies to building owners and specifies:

- the need for proper identification of asbestos hazards
- how to assess the risk
- responsibilities
- how to control hazards
- how to choose a removalist
- proper demolition and disposal.

Code of Practice for the Safe Removal of Asbestos (NOHSC 2005b) applies to those involved in the task of safely stripping asbestos. The important aspects covered include:

- construction of different isolation barriers
- respiratory protective equipment for asbestos removal work
- purpose and use of decontamination units (construction and operation)
- negative air pressure units
- inspection techniques for air leaks, smoke testing
- the purpose and value of air monitoring
- different kinds of stripping procedures for asbestos-bearing materials
- clean-up procedures and vacuum cleaner types
- correct asbestos disposal
- sealing systems for remaining fibres and barrier disposal
- value of asbestos fibre-in-air monitoring in final inspections.

Of particular interest in this document is the section on selection of the correct respiratory protection. It includes estimates of the expected asbestos fibre concentrations in air for different activities and the appropriate respirator to be worn. Some activities (e.g. dry stripping) involve fibre concentrations of several hundred fibres/mL or greater, justifying the stringency of the code. Unless properly controlled, asbestos stripping has the potential to produce a new generation of workers with asbestos-related diseases in the years to come.

Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres (NOHSC 2005c)deals with the sampling and analysis of airborne asbestos fibres, which are discussed in the following section.

5.8.6 THE RISKS OF ASBESTOS EXPOSURES

5.8.6.1 Asbestos dose

All three asbestos-related diseases discussed above are dose related. The greater the inhaled dose of asbestos fibre, the greater the risk of developing disease. Dose is represented by both the amount of asbestos in the air and the duration of exposure. This is usually expressed in terms of fibre/mL. years, that is, average airborne fibre concentration inhaled by the worker in fibres/mL of air multiplied by the length of time the worker is exposed:

$$\text{Dose} = \text{average airborne concentration of inhaled fibre} \times \text{years of work} \qquad \text{(Equation 5.1)}$$

However, using historical industrial exposures and response data in attempting to extrapolate today's risk (with its low exposures) presents considerable problems. It cannot be assumed that any of the asbestos diseases follow a linear dose–response model (i.e. there may be a threshold level below which asbestos exposure has no effect). Research on lung fibre contents of persons without asbestos disease has established the fallacy of the 'one fibre' theory (i.e. that a single asbestos fibre in a person's lungs can cause an asbestos-related disease). It has been shown that non-exposed people, who die at an old age due to non-asbestos related causes, can have large quantities of asbestos fibres in their lungs, presumably from environmental or unknown exposure.

The risk of developing asbestosis in any Australian processing industry now seems remote, since not only have previous industrial conditions been eradicated, but so too has most of the industry.

While the NOHSC exposure standard for asbestos in air is set at a level which will preclude any occurrence of asbestosis, it is intended primarily to prevent the rarer lung cancer and mesothelioma which can occur after considerably smaller exposures. The present standard for occupational exposure is 0.1 fibre/mL of air.

It is important, firstly, to know that 0.1 fibre/mL is a very low level by comparison to those of the 'bad old days', when typically an asbestos worker could be exposed to tens or hundreds of fibres/mL each working day. Secondly, it must nonetheless be remembered that these recommended levels are not intended to separate safe and unsafe conditions, any more than is the case with any other ES. These standards have been arrived at after extrapolating from quite old occupational hygiene environmental surveys and epidemiological data (remember the long latency periods). Further, the improved sensitivity of today's measurement techniques (about

10 times or greater sensitivity than 40 years ago) means that conditions of the 1950s and before were probably much worse than the few measurements available from that time suggest. In other words, old conditions of worker exposure may have been more in the hundreds to thousands of fibres/mL in terms of modern measurement methods.

The risk of lung cancer associated with today's airborne asbestos fibre concentrations also seems to be negligible, since the high levels of exposure which led to lung cancer no longer exist. Though difficult to obtain, epidemiological evidence has been able to distinguish lung cancer attributable solely to asbestos exposure without the confounding effects of cigarette smoking. Since it is clear that smoking far exceeds asbestos as a cause of lung cancer, the H&S practitioner's health promotion task in the workplace will be far more beneficial if directed towards altering lifestyle habits (e.g. promoting quit-smoking programs) and controlling asbestos exposure than controlling the latter alone.

Lastly, the risk of developing mesothelioma from the current low levels of exposure should be adequately controlled. The control levels for the two fibres strongly implicated in mesothelioma (crocidolite and amosite) were originally set at the lowest practical limit of detection by the standard optical method of measurement used in the late 1960s and 1970s. More recently, the ES for chrysotile has been revised to the same levels. Again, the occupational exposure data related to industry workers have generally shown high fibre exposures; the exposure data for those who developed mesothelioma outside the industry or in situations not directly associated with asbestos work have not been recorded. The methods of extrapolating linearly backwards from high to very low dose are again unreliable.

5.8.6.2 Practical assessment of the risk

The risk due to asbestos arises from inhalation of respirable asbestos fibres. A visual assessment of the workplace is the first important step. If a workplace looks dusty, no control procedures are in place and no respiratory protection is being used, workers could be excessively exposed to fibres. Correct fibre identification and fibre counting are the minimum requirements needed to assess the risk where asbestos-containing materials are being handled or disturbed.

The following steps indicate the basic procedures used in assessing the risk due to asbestos fibre exposure. Without extensive training, the H&S practitioner will not be able to conduct the identification or counting processes, but must be able to assess the information about the types of asbestos fibre present, asbestos fibre concentrations and risk factors.

1. Ascertain that asbestos is present

Asbestos is an established constituent in many products such as brake linings and asbestos-cement building products. However, for insulation materials particularly, asbestos is only one of many materials used. Other materials include:

- synthetic mineral fibre—fibrous glass, rock wool, refractory ceramic fibre
- vermiculite
- shredded cellulose (old newspapers).

Optical microscopy is most commonly and appropriately used to distinguish these other materials from asbestos fibres. Although many fibres have a macroscopic appearance which identifies them as non-asbestos (i.e. they are bright pink or bright yellow) others are difficult to detect by eye. If reliable information is not available, collecting and analysing a sample of the material may be necessary to confirm or eliminate the presence of asbestos.

2. Collecting an appropriate sample

A representative sample is needed for laboratory analysis. There may be more than one kind of fibre in the sample, including different kinds of asbestos. While collecting friable samples, wear an appropriate respirator. Collect enough material in order to sample all types of material present. For example, in sprayed applications, collect a sample from the surface right through to the bottom of the layer. On furnaces, different types of material may have been applied at different times. Usually 10–50 g will be sufficient. Pack the sample carefully in a sealed container so it will maintain its form and neither disintegrate nor cause contamination during transport or in the testing laboratory.

To differentiate old asbestos-cement building products from the newer asbestos-free materials, submit a piece about 5 cm square. Vinyl-asbestos floor tiles are difficult to analyse, and it is important to submit a minimum size of 10 cm square. Whole gaskets and friction blocks can be submitted for analysis; trying to sample them yourself may create unnecessary dust.

3. Have the asbestos fibre type identified positively

Crocidolite and amosite are more hazardous and generate higher airborne asbestos concentrations than chrysotile, so it is important to know which type of fibre you are dealing with. The kind of controls you may need to introduce might depend on fibre type, particularly in some abatement operations (e.g. only wet stripping should be used for crocidolite and amosite). Analysis should only be done by a consultant hygienist or a specialist laboratory accredited in this field by NATA, and to AS 4964 (Standards Australia 2004a). Capital costs of the equipment used in identification are significant, and a high degree of skill is essential.

Analysis requires the observation of a number of optical properties compared with complex diagnostic criteria to distinguish and identify different kinds of fibres.

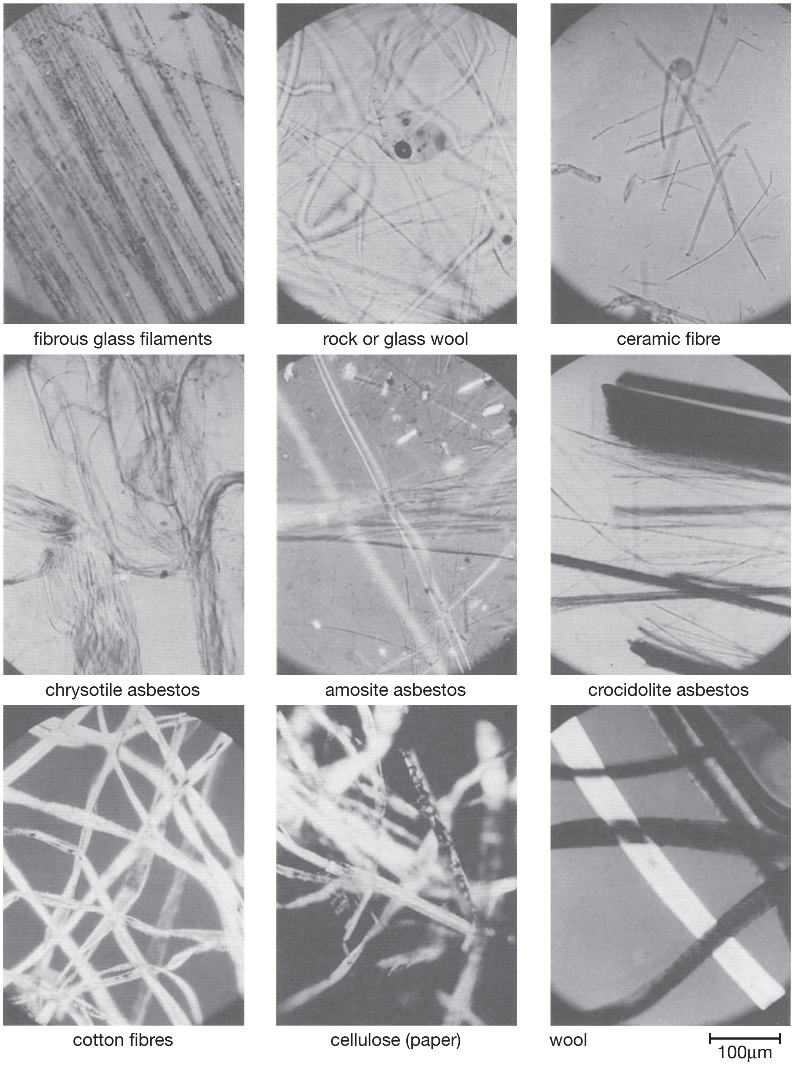
The analytical techniques used should include 1, 2 and 3 below, sometimes with any of 4–6 as confirmatory techniques:

1. Low and high power stereomicroscopy.
2. Polarised light microscopy (PLM).
3. Dispersion staining microscopy.
4. Infrared spectroscopy.
5. X-ray diffractometry.
6. Electron microscopy (scanning or transmission electron microscopy (SEM or TEM) incorporating X-ray analysis).

Examples of different types of fibres most commonly submitted for identification are shown in the photomicrographs in Figure 5.13. Note particularly the wavy shape of chrysotile fibres compared with straight amosite and crocidolite fibres. Synthetic fibres are commonly very large in diameter compared with asbestos fibres, or show long filaments of uniform diameter.

4. Does the source material contain much or only a little asbestos?

Experienced use of a stereomicroscope, PLM and dispersion staining methods can sometimes give very broad estimates of the amount of asbestos present in the sample. For instance, for control and removal purposes, it is useful to know that a sample contains say 80–100 per cent of amosite asbestos by weight, or perhaps less than 10 per cent. Some vermiculite used as an insulating material many years ago was mixed with a small amount of asbestos, usually less than 5 per cent chrysotile by weight.



fibrous glass filaments

rock or glass wool

ceramic fibre

chrysotile asbestos

amosite asbestos

crocidolite asbestos

cotton fibres

cellulose (paper)

wool

Figure 5.13 Photomicrographs of different types of fibre commonly found in workplaces

PLM and dispersion staining microscopy are also able to discriminate different asbestos fibres in mixtures and soils, and in general have a detection limit around 0.1 g asbestos/kg of sample, depending upon the type and condition of asbestos, and the complexity of the matrix. When a mixture of chrysotile and other asbestos fibres is detected, the risk associated with handling the material is usually assessed on the basis of the more hazardous type of fibre. X-ray and infrared spectrophotometric techniques are not able to differentiate between the non-fibrous form of the asbestos minerals and the fibrous form. However, combined with a technique to ensure that the fibrous form is present, X-ray and infrared spectrophotometric techniques with spectral subtraction facilities are able to differentiate between types of asbestos in mixtures, although they are not suitable for identifying trace levels of fibres in a mixture. SEM or TEM, although specialised and expensive and requiring skilled interpretation, can provide useful information on the different types of fibres when unequivocal identification by the traditional methods is not possible.

5. What is the condition of the asbestos?

The risk depends on the amount of fibres released into the workplace. Ascertain the state of the asbestos, because this is crucial to its control. Some asbestos-containing materials release almost no fibres to the workplace (e.g. asbestos-cement sheets in situ, sealed gaskets, vinyl-asbestos floor tiles, encapsulated fireproofing, some resin-bonded friction materials).

Other asbestos products can release considerable amounts of fibre, particularly loose forms of insulation. If the asbestos-containing material appears to be in poor condition, it probably needs replacing because it is failing to do the job it was intended to do. It is also more liable to shed fibres as it ages because of failing adhesion.

6. What is the procedure for handling the material in the workplace?

Using processes which minimise airborne fibre will reduce the risk. Use of wet dust-suppressing methods is important, especially for removal processes.

7. Are there any control procedures or respiratory protection in place?

Control procedures are crucial to the safe handling of asbestos. Workplace methods which prevent generated dust from escaping are the primary means of control. Respiratory protection is only added when dust control procedures cannot control the fibre release. Refer also to Section 5.8.5.3 on asbestos removal.

5.8.7 AIR SAMPLING FOR ASBESTOS

Almost all air sampling for asbestos in the occupational environment in Australia is carried out according to the *Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres* (NOHSC 2005c). Some electron microscopy is employed for special environmental investigations. It is important that the H&S practitioner understands the results the membrane filter method produces as well as its limitations. Although some other laboratories may claim to be able to conduct this work, laboratories accredited by NATA should be sought as first preference. Asbestos-removal regulations in most jurisdictions require that monitoring be conducted, and that it conforms to the requirements of the Guidance Note (NOHSC 2005c).

Airborne dust is collected on a membrane filter with a pore size of 0.8 µm, usually housed in a three-piece conductive cowl as shown in Figure 5.14. After sampling, the filter is rendered transparent and mounted on a microscope slide together with a cover slip. A phase-contrast optical microscope is used to count the number of fibres, geometrically defined as those which are at least 5 µm in length, less than 3 µm in diameter, and with a length to diameter aspect ratio of 3:1 or greater. One of the disadvantages of the optical counting method is that it cannot distinguish between true asbestos fibres and other fibres such as fine cellulose or ceramic fibres, which leads to conservative estimates (i.e. overly high concentrations) for environments containing mainly non-asbestos fibres. False positives will almost certainly be obtained even if the air sample derives from an asbestos-free environment, because of the presence of fibres from plant matter, carpets, fabric and clothes.

Figure 5.14 Asbestos and SMF sampling cowl, assembled and disassembled

5.8.7.1 Exposure monitoring

The membrane filter method was initially developed for measuring fibre levels in workplaces using asbestos. In any such work environment there was usually a mixture of dusts, of which most were asbestos fibres.

In Australia today exposure monitoring (previously known as occupational sampling) is unlikely to be needed because of the ban on asbestos use. If it is required, then advice from a laboratory or hygiene group which has significant experience in the methodology should be sought.

5.8.7.2 Control monitoring

Control monitoring (previously known as para-occupational sampling) employs the membrane filter method and is used in three ways:

- around the outside of an isolation barrier to ensure maintenance of seal
- to check on continued optimum performance of the filters on a negative pressure air fan attached to an isolating enclosure
- to provide final clearance monitoring after asbestos stripping.

Control monitoring can provide estimates of fibre concentration to about 0.01 fibre/mL.

A control level of 0.01 fibres/mL has been recommended by NOHSC for control monitoring outside asbestos-removal work areas. In some instances, industry and/or union agreement set additional action levels such as 0.02 and 0.05 fibre/mL, which if breached require increasingly stringent investigative and corrective action to be implemented.

5.8.7.3 Environmental sampling

For special investigations at very low fibre concentrations, electron microscopy, both scanning electron microscopy (SEM) and transmission electron microscopy (TEM), can be used. These methods have the added advantage that fibres can be positively identified by X-ray analysis. They also permit the differentiation of other fibres from asbestos, and the detection of fibres which are too small to be seen by standard optical phase-contrast microscopy. Special sampling and preparation techniques are needed.

SEM and TEM are not used routinely anywhere in Australia for exposure or control monitoring because of the high cost of both equipment and analysis. There are no standards for environmental asbestos in air.

5.9 FIBROUS DUSTS—SYNTHETIC MINERAL FIBRE

5.9.1 Types of synthetic mineral fibre

For a mixture of health-related, technical and economic reasons, much of the asbestos-based insulation materials have been replaced by synthetic mineral fibre (SMF, once called man-made mineral fibre). The properties of many SMFs means they can also be used in applications where asbestos could not (e.g. glass fibre reinforcing). SMFs have been around for about 60–70 years. Some initial concern that SMF might turn out to have effects similar to asbestos has proved largely unfounded. There are some problems in the workplace because it has the ability to cause contact irritation, largely due to the fibres being rather coarse. The major commercial types of SMF are shown in Table 5.3.

Table 5.3 Major commercial types of synthetic mineral fibres

Type	Raw material	End product examples
Fibreglass	borosilicate glass	insulation batts blankets and preformed sections continuous filament reinforcing fibres
Rockwool	basalt + fluxes	insulation and acoustic batts, tiles and preformed sections
Ceramic fibre	alumina + silica	blanket, boards, modules, plasters, textiles etc.

Primarily, most SMFs have a rather large fibre diameter compared with asbestos fibres. **Continuous filament glass fibres** are used in textiles, and to reinforce plastics and concretes in typical applications such as swimming pools, boats, surfboards and plumbing materials. Typical diameters range from 5 to 30 µm, depending upon the product, with very few or no respirable SMFs present. There is generally a narrow range of fibre diameters in any single product.

Glassfibre or **glasswool** is mainly in the form of insulation mats or blankets, with a small percentage of respirable size fibres (less than 3 µm diameter), even though most fibres are in the range of 5 to 15 µm diameter. **Rockwools** (or **slagwools**) contain fibres in a similar size range as glasswool, except for a larger percentage of respirable sized fibres.

Ceramic fibres are alumino-silicates, and found mainly in the form of insulation blankets. Common trade names are Kaowool® and Fibrefax®. The diameter range is from sub-micrometre to around 6 µm, with a large proportion of respirable fibres. Ceramic fibres are required for high-temperature applications.

Fibre-in-air concentrations for SMF are usually less than 1 fibre/mL unless hygiene practice is poor. Personal exposures for workers installing building insulation materials in attic spaces and walls are generally low for inhalation of dust and respirable fibres from slab materials of mineral wool or fibreglass, but high from loose-fill materials. Ceramic fibre removal work can result in exposures up to 18 fibres/mL.

5.9.2 HEALTH EFFECTS OF SMF

The major acute health effects from exposures to SMF are skin, eye and upper respiratory tract irritation, especially if SMF is disturbed close to a person, causing coarse fibres to be generated. At greater distances (i.e. more than several metres), the coarse fibres settle, leaving less irritating fine fibres in the air.

Garments with close-fitting collars and cuffs are useful to reduce skin contact and hence skin irritation. Exposure to high airborne dust concentrations can be successfully prevented by Class P2 particulate filter respiratory protection. In most instances, Class P1 particulate respiratory protection is sufficient.

With regards to the chronic lung diseases, the NOHSC Expert Working Party on SMF (1989) concluded that:

- SMFs are significantly less potent health hazards than chrysotile (white asbestos)
- SMF fibres are not carcinogenic to humans
- there is no risk of lung fibrosis from SMF
- there is no risk of mesothelioma
- there was a slight increase in lung cancer exposures during early years of the rockwool and slagwool industries, most likely due to carcinogenic oils and binders used during the manufacturing stages; glasswool and glass filament industries appear not to be implicated.

In 2002, the International Agency for Research on Cancer (IARC 2002) reviewed available epidemiologic data on SMFs and determined that:

- special purpose glass fibres such as E-glass and '475' glass fibres are possibly carcinogenic to humans (Group 2B)
- refractory ceramic fibres are possibly carcinogenic to humans (Group 2B)
- insulation glasswool, continuous filament, rock (stone) wool and slagwool are not classifiable as to their carcinogenicity to humans (Group 3).

SMF fibres do not remain in the lung very long because they dissolve in the highly acidic lung fluids. Biosoluble glass fibres have now been developed that dissolve in the lung even quicker than normal glass fibres. While this development is an attempt to further dissociate glass fibres from asbestos fibres in terms of physical properties and health effects, the clearance rates of any type of glass fibres are very rapid in comparison to asbestos fibres.

The NOHSC generic standard for SMFs is 0.5 fibres/mL.

If a workplace is involved in a significant amount of SMF handling, the NOHSC *Technical Report and Guidance Note* (1989) should be consulted. This publication also provides guidance on a membrane filter method with many similarities to the asbestos monitoring method (NOHSC 2005c).

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6. Metals in the workplace

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6.1 INTRODUCTION

The world's industrial and pre-industrial civilisations have depended in numerous ways on metal ore extraction and metal fabrication. Coinage, precious metals, the implements of war and industry, since the bronze and the iron ages have all been linked with occupational health hazards. During the industrial revolution and more recently in the technological age of the 20th century, metals have been implicated as the cause of occupational disease in many industries.

The toxic nature of metals and metal salts has also long been recognised, with lead and arsenic compounds often being favoured poisons. Almost all of us today are aware of the possibility of lead poisoning in children who may eat or chew the sweet-tasting lead paint flakes in old houses. The Mad Hatter in Lewis Carroll's *Alice in Wonderland* may have been 'mad' due to mercury poisoning; psychotic symptoms were common among workers in the fur and hat-making industries in the early 19th century due to excessive mercury exposure (see Section 6.9).

6.2 MAJOR METALS OF WORKPLACE CONCERN

This chapter examines the more toxic metals that are most commonly encountered, namely lead, cadmium, mercury, chromium, zinc and nickel, and the metalloid arsenic. (Metalloids have properties of both metals and non-metals.) The following aspects are covered for each of these materials:

- typical occurrence and use
- basic toxicology
- assessment in the workplace
- typically used control procedures.

A few less occupationally significant metals such as aluminium, beryllium, cobalt, copper, manganese, selenium and thallium, and the metalloids antimony and boron, are examined in lesser detail.

6.3 NATURE OF METAL CONTAMINANTS AND ROUTES OF EXPOSURE

Extraction, fabrication and widespread use of metals and their salts produce hundreds of situations with potential exposures. Because most metals and their salts are solids, most workplace exposure to metals and metal salts occurs through inhalation of their particulate (or aerosol) forms (i.e. dust, fume or mist). However, the contribution of ingestion should not be overlooked, as it is possible to transfer significant amounts of metals into the mouth during smoking and eating when personal hygiene is inadequate.

Mercury, a few metal hydrides (e.g. arsine, stibine) and some organometallic compounds are the common exceptions to the generally solid state. These are either gases or can exert significant vapour pressure at room temperature to be present in the vapour state. In such cases, the metal can be inhaled as a vapour.

Some significant workplace exposures also occur via the skin. Mercury salts, thallium and organometallic liquids can penetrate skin, and metals and metallic salts can enter the tissues through damaged skin, cuts, abrasions, etcetera. In some cases, the skin is itself the target organ and so direct skin contact is a route of exposure (e.g. nickel and other skin-sensitising metals).

Processes giving rise to metals in a form that can be absorbed are:

- metal ore extraction (e.g. mining of iron ore, manganese, lead, zinc, copper, uranium, etc., and their subsequent processing prior to smelting)
- metal smelting (e.g. arsenic, cadmium and selenium liberated in lead and zinc smelting, and mercury liberated in gold refining)
- metal founding (e.g. lead, brass)
- metal machining (e.g. beryllium drilling, grinding or polishing, and cobalt in dental prostheses)
- hot metal processing (e.g. hot zinc galvanising, metal recycling)
- welding, soldering, brazing and thermal cutting of metals (producing potentially hazardous metal fumes of cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, titanium, vanadium and zinc)
- handling powders of metal salts (e.g. lead battery manufacture, zinc and copper oxide manufacture, lead stearate use in PVC pipe manufacture).

6.4 METAL TOXICITY

The forms in which the metals exist are important. Metals can exist as the native material (e.g. chromium metal) or as different salts (e.g. chromium oxide), and the metal ion may exert different toxic effects depending on its form. Effects may range from dermatitis through neurotoxic effects to cancer. Some exposure standards have different exposure limits depending on the form of the metal, its chemical valency, or whether it is in the form of an inorganic salt or organometallic compound (e.g. chromium, nickel).

Assessing the toxic dose of various metals is often more complicated than with other poisons. Indeed, some metallic elements are essential to human existence in cellular function, bone structure or blood and enzyme systems. Fourteen metals, including sodium, potassium, calcium and magnesium, are involved in basic body building blocks. Trace elements, including zinc, selenium, iron, cobalt, arsenic and copper, are all essential in the right amounts to human life—they have a 'window of life' series of concentrations, higher and lower concentrations being detrimental. Further, it should not be forgotten that a number of metal-based compounds, themselves potentially poisonous to humans, have found great service in pharmacologically active drugs, including the early anti-syphilitic drugs, mercurochrome and platinum-containing cytotoxic (anti-cancer) drugs.

6.5 ASSESSING EXPOSURE TO METALS IN THE WORKPLACE

Most workplace monitoring for metals requires sampling for dusts and fumes. In the case of electroplating, some metals such as chromium and nickel become airborne as mists. These mists are monitored in a similar fashion to dusts and fumes containing metals. However, monitoring for some metals or their compounds (e.g. mercury vapour, arsine and stibine) requires special techniques.

Because similar sorts of air monitoring processes are used for most metals and metallic compounds, a procedure is detailed for only one metal, lead. As the toxic effects of metals often occur due to a combination of absorption from the lungs and ingestion after deposition in the nasopharyngeal (nose and throat) region, the inhalable fraction of the particulate is most often appropriately sampled (although in some cases that will be explained later, the respirable fraction should also be sampled). The reader is referred to Chapter 5, Aerosols, for other practical details, or to AS 2985 (Standards Australia 2004a) on gravimetric determination of respirable dusts and AS 3640 (Standards Australia 2004b) on gravimetric determination of inhalable dusts, for more complete procedures.

Air monitoring may indicate compliance with the relevant exposure standard (refer to Chapter 3, The Concept of the Exposure Standard). However, to assess the exposure from all routes (inhalation, ingestion and skin absorption), biological monitoring of exposure may be necessary in particular circumstances to evaluate the accumulated dose experienced by individual workers. The general principles of biological monitoring are discussed in Chapter 8, Biological and Biological-effect Monitoring. Throughout this chapter reference is made to the National Occupational Health and Safety Commission exposure standards (NOHSC 2006), available from the web-based Hazardous Substances Information System (HSIS), the American Conference of Governmental Industrial Hygienists' TLVs® (ACGIH® 2006), the US Occupational Health and Safety Administration's PELs (OSHA 2003), and the UK Health and Safety Executive's WELS (HSE 2005).

6.6 METHODS OF CONTROL

Although metal contaminants are often present as dust, fumes or mists, control procedures vary greatly, depending on how the contaminant is generated. Also, some of the more toxic metals require greater effort to control (e.g. lead dusts require more stringent control procedures than iron dusts). The lead example (Section 6.7) provides the detail that may typically be required for an H&S practitioner involved in control of hazardous metals in the workplace.

Workers in industries where toxic metals such as lead, cadmium, mercury, arsenic, chromium, nickel and zinc are handled should be fully instructed about the nature of health hazards and the control procedures required to prevent hazardous exposure, including respiratory protective equipment (RPE) use and maintenance. Appropriate RPE must be selected. Hand washing and separate eating facilities must be provided and their use enforced to prevent any possibility of accidental workplace ingestion. The need to prohibit smoking in toxic metal handling workplaces must be equally stressed.

6.7 LEAD

6.7.1 USE AND OCCURRENCE

The soft, lustrous, bluish white, silvery, malleable metal is obtained by the smelting of ores containing lead sulphide (galena) or sulphate or carbonate ores. Lead ores often occur with zinc and other toxic metals such as cadmium in minor concentrations. Australia is one of the largest miners and exporters of lead, with Mt Isa and Broken Hill being typical lead producers. Industrial use of lead is greatest in the lead battery industry, but it also finds applications in automotive paints, solders, ceramic glazes, metal alloys (e.g. gun metal), bearings and lead shot.

Industrial workplaces where there is **potential exposure to inorganic lead** include:

- the lead mining and refining industry
- the battery industry, both manufacture and reclamation
- the radiator repair industry
- propeller grinding
- lead lighting
- non-ferrous metal foundries manufacturing gun metal or leaded bronzes (see also Figure 6.1)
- spraying lead-based paints
- sanding or torch cutting of lead-painted metals (e.g. bridge painters, demolition workers)
- gold and silver laboratory assayers
- indoor shooting gallery and rifle range operators
- house painters sanding some houses painted prior to the 1950s
- some ceramic glaze workers
- PVC pipe manufacturing using lead stearate as a stabiliser.

Organic lead exposure occurs in petroleum workers potentially exposed to tetramethyl or tetraethyl lead, although these are being phased out of use.

6.7.2 TOXICOLOGY

Lead is the metal of greatest risk for poisoning of workers and the general public alike. More is known about its toxic effects than for any other metal. Toxicity depends mainly on particle solubility and its size, since these determine how easily it is absorbed. The greatest hazard in the workplace has typically been inhaled lead, either as particulate (dust) or as very fine lead fume, but the contribution of ingestion can be significant due to smoking and eating where personal hygiene is poor. Some of the inhaled dust and fume will also ultimately be swallowed following lung clearance mechanisms. Soluble lead salts are very toxic if swallowed. The smaller the particle size the more rapid its absorption, hence the more acute and severe the toxic effect. Thermally-generated fumes of the metal are more often involved in lead poisoning; on inhalation, fumes can

Figure 6.1 Brass founding may result in some exposure to lead fume

pass easily through the lung alveolar wall directly into the bloodstream. These fumes contain the easily soluble lead suboxide, common in the grey fume that occurs in and around lead smelters and brass foundries. For inorganic lead, absorption through the skin is negligible.

Once in the body, lead is transported in the bloodstream to all body tissues, and is predominantly stored in the bones of the skeleton (in the place of calcium). Mobilisation of lead from bone to blood is slow and can lead to slight elevations of blood lead for many years after exposure ceases. Excretion of absorbed lead from the body occurs primarily via the kidneys in urine. Blood lead levels are expressed in micromoles per litre (µmol/L) or micrograms per 100 ml or decilitre (µg/dl) and are a good reflection of absorption of inorganic lead into the body.

Lead is a neurotoxin which has been implicated in affecting intellectual development in the young (exposed to lead during gestation and early childhood) and can cause nerve conduction velocity decrease. Lead has also been associated with kidney dysfunction, increased blood pressure problems and sperm abnormalities. Other serious effects can accompany acute and chronic lead intoxication. Historically, the major toxic effect of lead has been on the haemopoietic (blood) system, resulting in anaemia. At very high lead absorption levels, which are no longer typical, symptoms can include constipation, abdominal pain, blue line on gums, convulsions, hallucinations, coma, weakness, fatigue, tremors and wrist drop.

6.7.3 STANDARDS AND MONITORING

Hazardous substances regulations require lead monitoring. Two types of monitoring are used:

- air monitoring in the workplace for lead
- biological monitoring of the worker for blood lead level.

6.7.3.1 Air monitoring

Adequate control of exposure to airborne lead should be employed to maintain workplaces within the NOHSC ES-TWA of 0.15 mg/m^3. However, the ACGIH® has a TLV®-TWA of 0.05 mg/m^3 for lead and its inorganic compounds, which is intended to maintain worker blood lead levels below 30 µg/dl (1.45 µmol/L). Monitoring provides information about:

- effectiveness of control measures
- reasons for some high blood lead levels
- specific work factors which may be hazardous
- correct level of control intervention required (e.g. local exhaust ventilation (LEV) or respiratory protective equipment (RPE)).

Air monitoring has to be undertaken as personal sampling, by a method conforming to AS 3640 (Standards Australia 2004b). The basic principles are:

- Workplace air is sampled using an IOM sampler or equivalent (Figure 5.7a and b) fitted in the worker's breathing zone using a portable monitoring pump running at 2 L/min attached to the worker's belt or a pump harness.
- The particulate or fume is trapped on an appropriate membrane filter.
- The sampled material is dissolved in nitric acid.
- The amount of lead is measured by atomic absorption spectrometry.
- The resultant concentration of lead in the air is calculated taking into account the sample volume.

Analysis for lead requires laboratory facilities. Most H&S practitioners will probably need to limit their involvement to sampling and the subsequent calculations and reporting.

6.7.3.2 Biological monitoring

Air monitoring may indicate compliance with the ES. However, monitoring the worker for blood lead level may still be necessary where:

- it is required by regulation
- there may be accidental uptake (e.g. via smoking or eating)
- workplace control of the lead hazard has failed
- work task factors (e.g. irregular duct cleaning) might still result in increased exposure to lead
- workers have a past history of excessive exposure to lead
- primary control processes are not used and RPE is the only defence
- a health and safety inspector requests it.

Biological monitoring for lead represents more than just checking hygiene in the workplace. It is an active and necessary intervention in maintaining the health of exposed workers, ensuring that deleterious levels of lead absorption do not occur. Wherever lead is used, some lead exposure inevitably occurs. Symptoms relating to lead absorption do not appear in most workers if the blood lead level can be kept below the action level chosen (e.g. 1.45 µmol/L or 30 µg/dl of blood). However, specific action levels may not apply to all workers. Lead is foetotoxic and lower levels of exposure will be necessary to protect developing unborn children. NOHSC has issued recommendations relating to lead exposure for women of childbearing age (NOHSC 1994). For females of reproductive capacity, a 'lead risk job' is one in which blood lead is likely to exceed 20 µg/dl (0.96 µmol/L), while for pregnant or breastfeeding women it is 15 µg/dl (0.72 µmol/L).

Measurement of pre-existing blood lead levels may be required under lead regulations prior to the commencement of work in a lead risk job. There are Australian Standards® for the sampling and analysis of blood for lead. These are AS 2636 (Standards Australia 1994), AS 2411 (Standards Australia 1993a) and AS 4090 (Standards Australia 1993b). Some other test indicators of the biological effect of lead, such as zinc protoporphyrins (ZPP), can be used to supplement the basic blood lead measurement but they are not generally used in routine surveillance.

NOHSC (2004) recommends a complex regime of actions based on blood lead. For example, monitoring frequency can vary from every 6 months when less than 30 µg/dl, to every 6 weeks if greater than 40 µg/dl (1.93 µmol/L) for all but females of reproductive capacity, where 10 µg/dl (0.48 µmol/L) will trigger 6-weekly monitoring. Removal from exposure occurs at greater than 50 µg/dl (2.41 µmol/L) for males, with return to work allowed only when blood lead is less than 40 µg/dl. Some companies use lower blood lead action levels than those recommended by NOHSC; for example, for male workers:

- an acceptable level is <15 µg/dl; repeat monitoring in 6 months
- the level triggering counselling and review of control measures is 30 µg/dl
- repeat blood test in 1 month and measure ZPP or use other effect test
- the transfer level is 40 µg/dl; repeat in 1 month and measure ZPP
- the return level is 30 µg/dl; with ZPP below 7 µg/gm haemoglobin.

Testing of urine for lead level is not a good indicator of exposure or body burden for inorganic lead because it is cleared from the blood and bone at quite different rates. However, lead in urine monitoring is the test of choice for assessing exposure to organic lead compounds such as tetraethyl lead.

6.7.4 CONTROLS

Where lead in air or blood lead levels indicate that exposure is deleterious, the reason for the excessive exposures needs to be determined and appropriate controls instituted. Control of both the inhalation and ingestion routes will usually be required to achieve good control.

Lead is essential in many industries. Substitution or a change in form of the lead should always be considered. The possibility of elimination or substitution is limited but has occurred in a number of applications, including fishing weights and some PVC stabilisers. In addition, changing the form of the material, such as using pelletised forms of lead stabilisers instead of fine powders in PVC pipe production, reduces the probability of lead becoming airborne. As lead fumes are generated at more than 450°C, reducing the temperature of the molten metal will reduce airborne exposures.

The most common secondary control procedures, with examples, are:

- Enclosing processes to control dust or fume:
    - lead alloying plants and lead oxide furnaces are completely enclosed to prevent any escape of lead dust (Figure 6.2a).
- Using dust minimising techniques:
    - keeping process materials wet
    - mixing spilled material with wet sawdust as a dust suppressant
    - using a vacuum cleaner (with an HEPA filter) in place of sweeping.
- Use of dust or fume extraction equipment:
    - fume extraction hoods or LEV over high temperature furnaces (>500°C)
    - portable hand tools fitted with dust extraction for sanding/grinding
    - exhausted enclosures in plate stacking in battery manufacture.
- Administrative controls:
    - permitting blood levels to increase above a background level but limiting the increase to a specified level
    - removing lead-affected workers from lead work
    - ensuring that eating, drinking and smoking do not occur in the workplace
    - maintaining good housekeeping
    - ensuring that facilities for good personal hygiene are provided and used.
- Use of RPE, the type of which will depend on the concentration of lead in the workplace atmosphere, how it is generated, the protection factor required and the physical demands of tasks being undertaken:
    - thermally produced fumes will require medium efficiency particulate (P2) filtration for air concentrations up to 10 times the ES-TWA (Figure 6.2b)

- higher concentrations will require the use of powered air purifying respirators with (P2) filters
- air-line respirators will be necessary for filling batteries in submarines.

Instruction, training and maintenance of monitoring and health surveillance programs are all very necessary in workplaces handling lead. Workers must also know and understand the hazards of handling lead. In addition to its toxic qualities, lead is heavy, hence manual handling of some lead products can require ergonomic considerations.

6.7.5 LEAD REGULATIONS

Lead is subject to regulation in most countries. In Australia, regulations in each state are based on the *National Standard [NOHSC:1012] and National Code of Practice [NOHSC:2015] for the Control of Inorganic Lead at Work* (NOHSC 1994). These embody the concepts of a lead process (certain conditions have to be met before the task is considered a lead hazard) and a lead risk job (having lead exposure which results in various blood lead levels—hence categories—depending on individual circumstances), with special requirements to observe equal employment opportunities for women and men. The requirements emphasise biological and air monitoring. Monitoring is followed up with a strict control regime. H&S practitioners involved in the assessment or management of lead risk jobs will need to know:

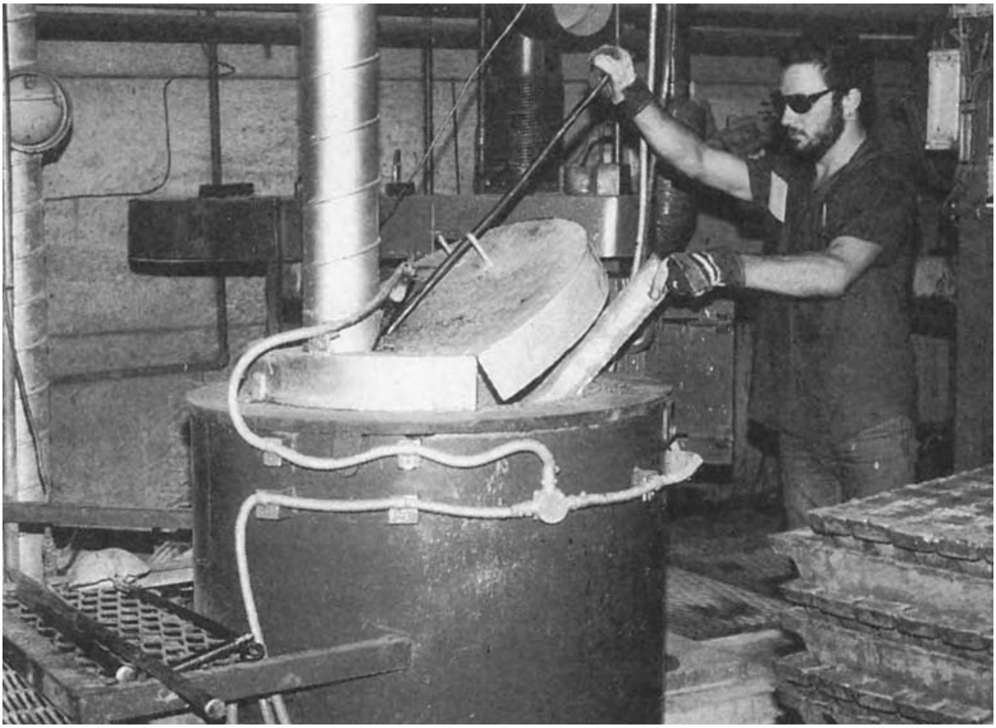
- how the operations produce lead dust or fume contamination
- the exposure to airborne lead in each job or similar exposure group
- the categories of lead risk job and the health surveillance requirements
- the blood levels of individual operators (subject to medical confidentiality)
- the control processes and the relative effectiveness of each
- procedures to undertake when lead action levels are exceeded.

For much of this work, the H&S practitioner will have to work in conjunction with a medical practitioner experienced in interpretation of lead exposure. The assessment of control measures may be facilitated by knowledge of the blood lead of individual workers. In order not to breach medical confidentiality it may be advisable to ask workers to sign a release form for their blood lead results. The H&S practitioner must ensure that this information is used only for the purposes of assisting the workers to control their lead absorption.

6.8 CADMIUM

6.8.1 USE AND OCCURRENCE

The white, ductile metal cadmium finds a number of industrial uses because of its low melting point, conductivity and resistance to corrosion. It is used in the manufacture of nickel-cadmium (NiCAD) batteries, in cadmium electroplating of steel to provide a protective coating, in welding rods, brazing solders, in low melting point safety valves



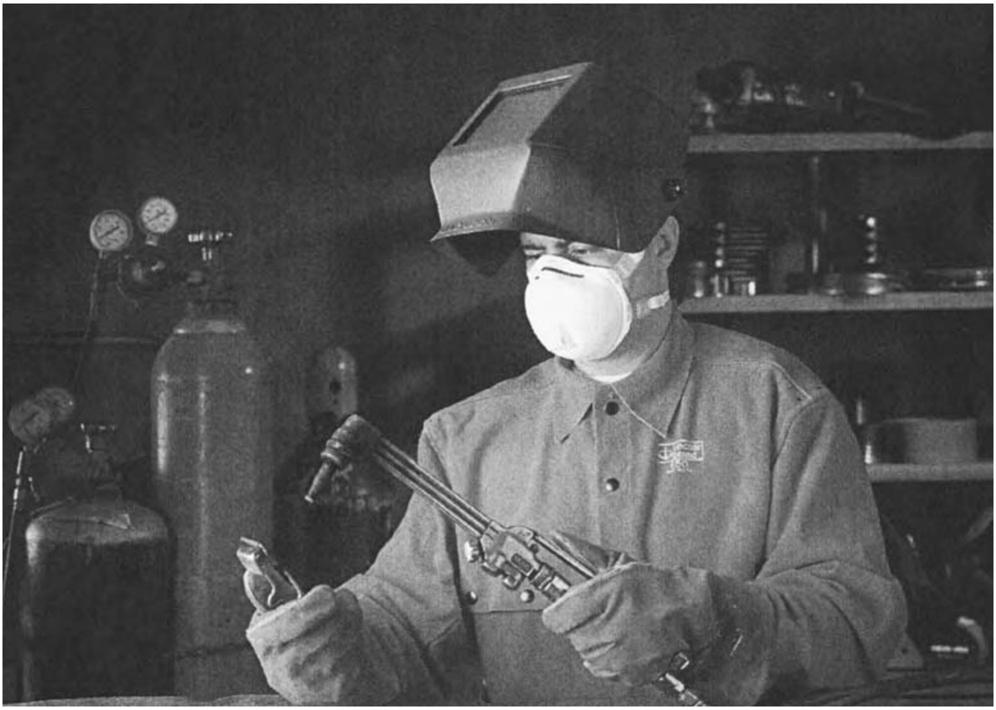


Figure 6.2a (top) and 6.2b Examples of fume control and RPE against thermally generated lead fume: (a) full extraction on a lead-to-lead oxide converting furnace; (b) P2 particulate filtration respiratory protection

and in metal alloys. Its salts are also widely used in pigments, rubbers, paints, inks, plastic stabilisers, fireworks, rectifiers, solar cells and television phosphors.

Exposure occurs principally by inhalation, usually from processes that involve handling the material or its salts as powders, or where thermally-generated fumes occur in the workplace. Recovering cadmium from NiCAD scrap batteries and welding of cadmium-plated metals are also potential sources of exposure. Accidental ingestion is rare.

6.8.2 TOXICOLOGY

Cadmium shows both acute and chronic toxic effects. Cough, headache, eye irritation, chill and fever, with chest pain, may follow acute inhalation of a cadmium fume, with possible delayed lung damage (pulmonary oedema, pneumonitis). A metal worker overexposed to cadmium fume may develop a typical metal-fume fever in the evening (or even days later), and not relate it to work carried out during the previous day.

Chronic effects of exposure include kidney damage, sometimes with formation of kidney stones as well as respiratory system damage (fibrosis). Cadmium is considered a suspected human carcinogen. It may contribute to the development of lung cancer, but evidence in workers has been difficult to interpret due to confounding exposures.

6.8.3 STANDARDS AND MONITORING

The NOHSC exposure standard for airborne cadmium as the oxide, fume or metal is 0.01 mg/m^3, set to prevent kidney disease in long-term cadmium workers. However, the US Occupational Health and Safety Administration (OSHA) has set a lower limit of 0.005 mg/m^3, while the UK HSE has a limit of 0.025 mg/m^3 (HSE 2005). ACGIH® recommends the 0.01 mg/m^3 limit, but has also adopted a respirable particulate fraction exposure standard of 0.002 mg/m^3, set to minimise the potential for lower respiratory tract accumulation of cadmium that could induce lung cancer.

6.8.3.1 Air monitoring

To conduct workplace monitoring, personal breathing zone sampling with an IOM inhalable dust sampler or equivalent is required, and a respirable dust sampler. Other practical details are similar to those outlined for lead sampling. Laboratory analysis is required and is described in method MDHS 10/2 (HSE 1994) on determination of inorganic cadmium and its compounds in air.

6.8.3.2 Biological monitoring

Cadmium is a scheduled hazardous substance for which health surveillance must be provided if the risk of exposure is found to be significant. The health surveillance includes respiratory function testing, questionnaire and urinary and blood testing.

For workplaces that use cadmium regularly, blood testing for cadmium may be necessary. The biological exposure index (BEI®) for blood cadmium is 5 μg/L (ACGIH® 2006). Alternatively, urinary cadmium can be measured, for which the BEI® is 5 μg/g creatinine. Urinary excretion of cadmium is related to body burden, recent exposure and renal damage, hence interpretation of urinary cadmium levels is not simple.

6.8.4 CONTROLS

The highly toxic nature of cadmium requires its use in the workplace to be extremely well controlled. Elimination and substitution are rarely feasible, so prevention of airborne dust and fume production is mandatory by measures such as minimising temperatures in welding and soldering, and using mechanical cutting instead of thermal cutting of cadmium-coated products.

Where LEV is employed, it will need to be of a high standard to control the dust or fume hazard. The filtration and recovery of cadmium or its salts from extraction system discharge also requires consideration.

RPE for use with cadmium or its salts may be required in certain work operations where higher controls (i.e. engineering controls, ventilation) are impractical or cannot adequately control the hazard. Respirators with medium particulate filtration efficiency (P2) may be used for airborne concentrations up to 10 times the ES-TWA (i.e. up to 0.1 mg/m^3). However, high temperature soldering/brazing or thermal cutting with cadmium-containing materials can generate concentrations up to 5000 times the ES (it evaporates significantly at its melting point). Mistaken reliance on filtration RPE could have disastrous consequences. For thermally-generated fumes one of the following is needed:

- primary fume/dust control *and* medium efficiency particulate filtration (P2)
- an air-supplied system with back-up high efficiency particulate (P3) protection, while ensuring there is no subsequent bystander exposure.

All workers involved with cadmium in the workplace require thorough instruction on methods of safe handling and use. Particular attention must be paid to the use and maintenance of RPE whenever its use is required, and to the need for biological monitoring.

6.9 MERCURY

6.9.1 USE AND OCCURRENCE

Metallic mercury is a silvery heavy liquid that is obtained from roasting cinnabar ore. Use of mercury-containing compounds has had a long history, dating at least from Roman times. In the 17th century, its use in the form of mercury nitrate in the hat trade for carrotting of fur was widespread. Mercury has found more recent use in submarine ballast, mercury fulminate explosive detonators, barometers, thermometers, pressure pumps, electric lamps and mercury rectifiers, chlor-alkali cell electrodes, dry-cell battery manufacture, electrical switches, chemical catalysis, dental amalgams and in the extraction of gold from ores. Cyanide leaching of low-grade gold and silver ores also collects any mercury contained in the ore, which is volatilised off by heating during further processing for the gold. It also finds use in mould and fungus inhibitors for wood, paper and grain, some medicinal preparations and in paints for inhibiting marine growth on hulls of ships. It can still be found providing the frictionless float bearing in a few lighthouses. There are pressures to severely limit the use of mercury, mainly due to its tendency to accumulate in brain and foetal tissues, and in breast milk, with consequent fears of adverse effects on reproduction and children.

6.9.2 TOXICOLOGY

Liquid mercury vaporises readily at room temperature and hence inhalation of mercury vapour is the prime route of entry, although skin absorption can also occur for both the metal and its compounds.

Cases seen in the past of gross poisoning with skin ulceration and gastro-intestinal symptoms are not seen nowadays. Accidental poisonings of children (from mercury compounds and mercury metal) still occur but are rare.

Mercury accumulates mainly in the brain and kidneys. The main target organ is the central nervous system (including the brain), although kidney damage may also occur with some mercury salts. The toxic action of mercury compounds occurs by precipitation of protein and inhibition of sulphydryl enzymes. These cause central nervous system damage, resulting in headache, tremors, weakness and psychotic disorders including shyness, irritability and excitability. The classical mad hatter's disease, with its spidery writing and withdrawn behaviour, is typical of mercury poisoning, but it is rarely seen these days. For some, mercury sensitivity may develop, with skin reaction even to the vapour, causing contact dermatitis. Ingestion of organo-mercury compounds has resulted in a different type of central nervous system debilitation which is often irreversible. This occurred in Japan following eating of fish containing high levels of methyl mercury (so-called Minimata disease), and in the Middle East where mercury-treated seed wheat was eaten.

Recent data indicates that mercury can affect both male and female reproductive outcomes, including the ability to produce healthy children with normal cognitive and physical functions.

6.9.3 STANDARDS AND MONITORING

The NOHSC exposure standard for mercury vapour and inorganic mercury compounds is 0.025 mg/m^3, expressed as a TWA (NOHSC 2006). Note that mercury has a skin absorption notation. The same exposure standard is used widely (e.g. by the ACGIH® (2006) and the HSE (2005)). It has been set to minimise the potential for central nervous system changes and kidney effects, and to provide some assurance that the cognitive and physical functions of children are not adversely affected.

6.9.3.1 Air monitoring

Several methods are available for monitoring mercury in the workplace, all of which rely on the fact that mercury can be trapped and measured as a vapour. They are:

- indicator stain tubes (see Chapter 7, Gases and Vapours, Figure 7.2); this method is generally useful for exposures greater than the ES-TWA
- the direct in-field monitor (Figure 6.3, left) using ultraviolet detection or a gold film amalgam; this method is useful both above and below the ES-TWA
- impingement into an acid permanganate solution (Figure 6.3, right) followed by cold vapour atomic absorption spectrometry—the most sensitive method
- passive (see Chapter 7, Gases and Vapours, Figure 7.13) or active sampling (Figure 7.11) onto a solid sorbent device (using Hydrar® or hopcalite as the sorbent), followed by cold vapour atomic absorption spectrometry. This method is also useful both above and below the ES-TWA, and is the most commonly used. Refer to method MDHS 16/2 (HSE 2002) on determination of mercury and its inorganic divalent compounds in air.

Figure 6.3 Mercury monitoring methods: (left) portable gold film meter; (right) permanganate impinger method

6.9.3.2 Biological monitoring

Inorganic mercury is a scheduled hazardous substance. Health surveillance may be required if the risk from exposure to mercury is found to be significant, with any affected workers being immediately removed from further exposure. The preferred indicator of inorganic mercury absorption is its concentration in urine. ACGIH® recommends a BEI® of 35 µg/g creatinine, taken pre-shift.

Some mercury is normally contributed from the diet (e.g. from eating fish). Those exposed occupationally to mercury show elevated urinary mercury; background mercury levels of unexposed persons are generally less than 5 µg/g creatinine while levels above 35 µg/g creatinine are considered significant. Urinary levels of about 50 µg/g creatinine are seen after occupational exposure to about 0.04 mg/m^3 mercury in air. Blood mercury can be monitored, but sample collection is much more complicated than simple collection of urine samples, and interpretation of the significance of the results can be difficult.

6.9.4 CONTROLS

The primary methods used to prevent mercury uptake in the workplace are:

- Elimination of the use of mercury-containing equipment such as thermometers with non-mercury-containing alternatives such as alcohol thermometers or thermocouples. Mercury from mercury-in-glass thermometers that break in hot ovens will be rapidly evaporated.
- Substitution of mercury-containing processes wherever possible (e.g. use of composite restoration material in place of mercury dental amalgams; use of organic chemicals for fur carrotting; use of carbon in pulp gold leaching in place of the older styled mercury retorting; replacement of neon/fluorescent tubes that contain mercury).
- Prevention of vapour generation. Mercury evaporates readily, so it should be stored in closed, water-sealed containers. Where mercury metal is heated, the hazard is enormously increased, so operations such as welding or brazing on mercury-in-metal thermometers must be strictly controlled.
- Enclosure of processes where mercury vapours may be generated to prevent escape of vapours. Where not possible, LEV to a high standard is required. All mercury-contaminated air exhausted from a process should be routed through a mercury scrubbing device, using a sulphur- or iodine-impregnated carbon pack, or by bubbling the air into a tank that contains a mercury-complexing agent in conjunction with a de-mister. Mercury tends to condense in ventilation ducts. Having smooth-walled ducts that slope towards a gravity collection trap should control this condensation.
- Areas designed for handling mercury should be adequately designed to cope with spills, with impervious flooring (e.g. use epoxy, polyurethane or vinyl sheeting; wood or carpeting should be avoided) and bunded (built-up) edges to prevent dispersion of the small mercury droplets. Proprietary products (HgX®) or a paste of slaked lime and flowers of sulphur (1:1) can be used to assist in removing the metal from inaccessible and otherwise hard to clean cracks, crevices or in equipment, etcetera. Contaminated materials such as carpet are best discarded but disposal must be in compliance with local hazardous-waste requirements.
- Preventing mercury from spraying into small droplets that are difficult to coalesce and collect. Small droplets have a very large surface area and evaporate much more rapidly. Mercury should not be collected with a vacuum cleaner unless it is specifically designed for mercury. Any vacuum pick-up system must have an adequate mercury vapour trap.
- Personal protective equipment for mercury vapour is available and must be used when significant mercury spills have to be cleaned up. Respirators impregnated with an absorbent for mercury vapour can be used with relatively small spills.

Major spills will require air-line breathing apparatus, particularly if the ambient temperature is elevated. The use of overalls and gloves will be necessary if any skin contact is likely.

- Workers handling mercury should be instructed in the hazards of the material, adequate methods of containment and control, and in decontamination procedures should a major spill occur.

6.10 ARSENIC

6.10.1 USE AND OCCURRENCE

Arsenic, particularly its trioxide, finds a curious place in the disservice of man as a poison favoured by those with crime in mind. Metallic arsenic has a few industrial uses in alloying with lead for bearing alloys, cable sheaths or battery grids. In contrast, compounds of arsenic (oxides and complex salts with other metals) are widely used in the manufacture of weedkillers, insecticides, wood preservatives, antifouling paints and fungicides. Tobacco crops were once widely sprayed with arsenicals. A well-known copper-chrome-arsenic (CCA) preparation is widely used in the production of logs and timbers for outdoor and garden use.

The once popular use of arsenic compounds as paint pigments has been discontinued for obvious public health reasons, but they are still used in some fireworks. Arsenic has found new uses in high technology electronics processing for semiconductor doping and various radiation detectors. Workers in all these industries have potential exposure to arsenic or its compounds. Smelting of ores containing arsenic impurities (e.g. copper, lead and zinc ores) is also an important source of potential arsenic exposure.

Users of arsenic-containing agricultural chemicals are also at risk of exposure. End users of CCA-treated timber are not at risk, provided that timber offcuts are not burned (e.g. in barbecues). Burning can convert the timber lignin-bound arsenic to the volatile and hazardous arsenic trioxide.

6.10.2 TOXICOLOGY

The toxicity and action of arsenic and its compounds is varied, depending on its chemical form. Arsenic and its compounds can be both ingested and inhaled as dusts, and arsenicals can cause corrosive or ulcerative effects in the skin and mucous membranes. The major routes of entry in the workplace are by inhalation. Both acute and chronic effects can occur.

Acute effects include haemorrhagic gastritis, muscular cramps, facial oedema, peripheral neuropathy, corrosive actions and skin lesions.

Chronic effects include irritation to the nasal mucosa with penetration of the nasal septa in some workers exposed over long periods to low levels of arsenic dusts. Dermatitis may be observed, with heavy skin pigmentation and peripheral vascular disorders in some exposed populations who ingest arsenic-contaminated water.

Arsenic is also accepted as a human carcinogen, causing lung cancer (e.g. in smelter populations) and respiratory tract cancer (e.g. in those making arsenical pesticides).

Some skin cancers and hyperkeratosis are attributable to arsenic exposure, including via some therapeutic administrations. There is also evidence that, in addition to therapeutic administration, ingestion of inorganic arsenic is associated with skin cancer. There is also some evidence of liver cancer.

Arsenic is also one of a group of metals that forms a volatile hydride by reacting with nascent hydrogen (e.g. from contact with acids), so accidental generation of arsine can arise from arsenical contamination. Arsine, a gas with a garlic odour, is an extremely acute inhalation hazard. For example, in a Queensland case, several persons, including children, were affected when ground contaminated with old arsenical cattle dip came into contact with an acid source, probably superphosphate, and arsine was liberated. Onset of symptoms occurs within a few hours of exposure, with headache, giddiness, abdominal pain and vomiting. The urine is stained due to haemolysed, excreted blood cells. Anaemia and jaundice follow, which may result in kidney failure.

6.10.3 STANDARDS AND MONITORING

The NOHSC ES-TWA is 0.05 mg/m^3 for inorganic arsenic salts, the metal and its soluble salts, and 0.16 mg/m^3 (or the equivalent 0.05 ppm) for the gaseous arsine (NOHSC 2006). ACGIH® (2006) has the same exposure standard for arsine, but has a TLV®-TWA of 0.01 mg/m^3 for elemental and inorganic arsenic compounds, to minimise the potential for adverse effects on the skin, liver, peripheral vasculature, upper respiratory tract and lungs, including cancer. The ACGIH® has recommended that the arsine TLV® be reduced to 0.005 ppm.

6.10.3.1 Air monitoring

Monitoring methods depend on the form of the arsenic. The main methods of collecting the sample employ personal sampling, with a sampling pump connected to filter(s) or a solid sorbent tube.

Arsenic trioxide vapours (a major exposure in smelting) must be collected on filter papers treated with sodium hydroxide or sodium carbonate. Any sampling head suitable for use with treated filters will suffice. HSE method MDHS 41/2 (HSE 1995) and NIOSH method 7901 (NIOSH 1994) contain practical details.

Arsenic particulates are collected on mixed cellulose ester filters using the IOM sampler or equivalent. Refer to AS 3640 (Standards Australia 2004b) or MDHS 41/2 (HSE 1995) for sampling details.

Arsine is collected using a charcoal sorbent tube followed by analysis using atomic absorption spectrophotometry with graphite furnace, as detailed in NIOSH method 6001 (NIOSH 1994).

Most H&S practitioners should be able to conduct the sampling with appropriate training, but all the methods require laboratory analysis.

Simple direct reading indicator stain tubes (refer Chapter 7, Gases and Vapours, Section 7.11) are available for both arsenic trioxide vapour and arsine. These indicator tubes may require a very large number of pump strokes to be able to read the tubes at concentrations much lower than the ES-TWA. The gaseous arsine indicator stain tubes are more manageable, requiring only 20 strokes, with a measuring range of 0.05–3 ppm.

6.10.3.2 Biological monitoring

Inorganic arsenic is a scheduled hazardous substance and may require health surveillance if exposure is significant. Though air monitoring remains the most appropriate means of workplace surveillance, monitoring of urine in workers manufacturing arsenicals is recommended in order to review recent exposures. The preferred biological indicator of arsenic (elemental and soluble inorganic compounds) absorption is its concentration in urine. ACGIH® (2006) recommends a BEI® of 35 µg/L, taken at the end of the working week.

Normal unexposed workers have arsenic in urine levels below 10 µg/L in European countries, slightly higher in the United States, but around 50 µg/L in Japan. Seafood consumption can be a prime source of arsenic (mainly as organic compounds) for non-occupational exposure. A laboratory experienced in trace level arsenic determinations can advise on sampling procedure. Urinary analysis requires 200 ml preserved with 0.5 gm EDTA with sample refrigeration until analysis. Exposure to 0.01 mg/m^3 of arsenic in air for 8 hours will most likely result in a urinary concentration of about 35 µg/L. Workers should be asked about the amount of seafood eaten in the 48 hours before the test, and high quantities should be noted. Caution in interpretation of single high values in urine is necessary. In these cases a second sample should be taken, either after asking the worker to reduce seafood consumption or to analyse the second sample for both inorganic and organic arsenic species.

6.10.4 CONTROLS

A number of control procedures can be required when working with arsenic-containing compounds. Substitution of arsenic preparations in agriculture by organochlorine and organophosphate pesticides has markedly reduced the potential for occupational exposure. All processes handling powders should be totally enclosed. When this is impractical, a high standard of LEV must be employed to remove vapours and dust from the workplace.

Processes utilising arsine must be fully enclosed with extraction systems and reliable leak detectors employed. Accidental arsine generation in smelters and metal shops must be prevented by keeping dross dry and forbidding all hazardous reaction ingredients (acids, alkalis, zinc and aluminium).

Skin protection with impervious gloves is mandatory when handling liquids (e.g. in the CCA wood treatment industry; see Figure 6.4) where splashes to the hands and forearms are common. Face shields may also be required when working with solutions of arsenic salts.

Where RPE is required (i.e. engineering controls have not reduced air concentrations to required levels), careful attention is needed in its selection by taking account of:

- the nature of the arsenic hazard (dust, vapour or gas)
- the required minimum protection factor.

Figure 6.4 Gauntlet hand-arm protection is required when handling arsenic-treated timber

For example:

- Arsenic-containing dusts require particulate filter respirators with filtration efficiency (P1, P2 or P3) according to the concentration of dust in the workplace.
- Arsenic trioxide vapour requires a filter treated with the appropriate absorbent, soda lime, which can be used up to 1000 ppm only.
- Arsine requires supplied air with full-face mask. Normally, this would be for emergency use only where arsine is accidentally generated.

In addition to being fully instructed with regard to health effects and control techniques, workers need especially to regard health surveillance, which includes medical assessments, biological arsenic monitoring and skin examination, as central to their wellbeing when working with arsenic or any of its compounds.

6.11 CHROMIUM

6.11.1 USE AND OCCURRENCE

The hard grey metal chromium, obtained from chromite ore, and many chromium salts find use in many industrial applications. Chromium metal is extensively used as an alloy in stainless steel, special tooling metals, welding rods and electrical resistance wires. Chromium exists in several valency states, as II (chromous, basic), III (chromic, trivalent chromium or amphoteric) and VI (hexavalent chromium or chromate, acidic). The chromium II salts are relatively unstable and are not widely used. The chromium III and VI salts find wide use, the chromium VI salts because of their strong acid and oxidative properties. Chromium III salts are used most widely, including in the production of pure chromium metal and chromium VI compounds.

Typical workplace processes where chromium exposure can occur include:

- chromium electroplating
- MMA (manual metal arc) and FCA (flux-cored arc) welding of stainless steels
- aluminium anodising
- chromium-based timber treatments (CCA)
- tanning of leather hides
- manufacture and use of spray paints containing chromium salts as pigments or zinc chromate as a rust inhibitor
- use of chromium bichromates of ammonia, sodium and potassium as mordants in dyeing
- photography and photo-engraving
- manufacture and use of high temperature chromium-containing cements for aggressive environments (e.g. refractory products).

6.11.2 TOXICOLOGY

While the metal chromium itself is inert, the salts are irritating and destructive to tissues. Uptake of chromium in the workplace is mainly by inhalation. Chromium VI salts in particular are irritant, may cause dermatitis and skin ulcers, and in extreme cases cause ulceration and perforation of the nasal septum. Chrome 'holes' around fingernails, finger joints, eyelids or sometimes on the forearms may occur, though they are not proliferating and may be due more to the strong oxidative power of these materials rather than to the chromium itself.

Studies of work groups producing chromates, bichromates and chromic acid, however, have established that prolonged inhalation of chromium VI dusts causes lung cancer. Roasted chromite ore exposure may likewise cause cancer. For this reason, chromium VI salts are considered environmentally hazardous; many local government authorities require them to be converted to a reduced form prior to disposal.

Chromium metal, raw chromite ore and chromium III salts may cause respiratory tract and skin irritation, and dermatitis, but are not considered carcinogenic. In fact, some chromium III salts are essential nutrients.

6.11.3 STANDARDS AND MONITORING

Because of the different toxic effects depending on oxidation state of the chromium, there are different exposure standards proposed for different salts, as shown in Table 6.1. Note that the ACGIH® (2006) has recommended one lower standard. The ES-TWA of 0.5 mg/m^3 for the metal and the lower oxidation states is believed to be sufficient to minimise the potential for respiratory tract and skin irritation, and dermatitis. For chromium VI salts, the lower ES-TWA is primarily to protect long-term workers against increased risk of cancer in addition to respiratory tract and skin irritation, and dermatitis.

Table 6.1 Exposure standards for chromium and its salts

	NOHSC	**ACGIH®**
chromium metal	0.5 mg/m^3	0.5 mg/m^3
chromium II and III salts	0.5 mg/m^3	0.5 mg/m^3
chromium VI water-soluble salts	0.05 mg/m^3	0.05 mg/m^3
chromium VI insoluble compounds	0.05 mg/m^3	0.01 mg/m^3

Source: NOHSC (2006) and ACGIH® (2006)

6.11.3.1 Air monitoring

Air monitoring for chromium particulates requires personal sampling with an IOM inhalable dust sampler or equivalent (refer to AS 3640, Standards Australia 2004b, for details). Other technical details are fully covered in methods such as MDHS 12/2, *Chromium and Its Inorganic Compounds of Chromium in Air; Atomic Absorption* (HSE 1996a), MDHS 52/3, *Hexavalent Chromium in Chromium Plating Mists* (HSE 1998) and NIOSH methods 7600, 7604, 7024 and 7300 (NIOSH 1994).

Laboratory advice should be sought before attempting to monitor chromium, as a number of technical problems are present. Sampling chromic acid mists requires a non-metallic open-faced filter holder, and a filter (e.g. PVC) that will withstand the action of acid and not affect the stability of the chromium. Sampling of chromium in welding fume is critical with respect to time; the chromium oxidation state will depend on the welding technology (inert gas shielded or manual metal arc, etc.) and the time after thermal generation of the fume.

6.11.3.2 Biological monitoring

As chromium is a scheduled hazardous substance, health surveillance for chromium workers may be required depending on the significance of risk. Urine testing is required for those working with water-soluble chromium VI salts. ACGIH® (2006) recommends a BEI® of 25 µg/L for total chromium in urine, taken at the end of the shift at the end of the working week. A BEI® of 10 µg/L for total chromium in urine increase during a shift is also recommended. Annual physical examination with emphasis on the respiratory system and skin, and weekly inspection of hands and forearms is advisable if there has been significant exposure (e.g. greater than half the ES). Air monitoring provides a better indication of the level of exposure than blood or urinary monitoring.

6.11.4 CONTROLS

Control of chromium dusts in the workplace is paramount to preventing inhalation exposure. Enclosed systems and high quality LEV are priority control procedures.

In chromium electroplating, the chromium or chromic acid mists generated over air-agitated tanks require several levels of control:

- surface active additives to prevent formation of stable bubbles
- floating surface balls to prevent a large surface-to-air interface
- push-pull ventilation to capture any escaped mists (refer also to Chapter 4, Control of Workplace Health Hazards, Figure 4.23).

Skin protection is necessary where splashes of liquid can occur, or where dried salts can be picked up by sweat on the skin (e.g. leather tanning industry). A paraffin and lanolin barrier cream should be used as an added protection. A 10 per cent CaNa EDTA ointment should be applied to any cuts or abrasions contaminated by chromium salts (this converts all chromium VI to chromium III, which can be safely bound or chelated). Full impermeable protective equipment against accidental exposure should be used where appropriate in electroplating.

Because of carcinogenic considerations, RPE should be a last resort, to be used only when all other methods to control exposure have been exhausted (e.g. when stripping chromium cements inside a warm furnace flue). The choice of RPE depends on the following considerations:

- valency state of chromium (III or VI)
- airborne concentration of chromium
- protection factor required
- physical demands of tasks being undertaken.

Workers involved in handling chromium salts, chromium electroplating or welding of stainless steels should be fully instructed with regard to health effects and in the specific hazards of their particular task. Attention should be paid to safety measures and controls and their correct operation.

6.12 ZINC

6.12.1 USE AND OCCURRENCE

Metallic zinc is obtained by treatment (froth flotation and roasting) of zinc sulphide ore. Smelted zinc produces an impure grade suitable for galvanising, and electrolytically refined grade zinc is suitable for metal die-casting and moulding. Zinc reacts rapidly with oxygen to form a protective layer of zinc oxide, which prevents any further reaction. Zinc finds use in galvanising protection of steel and roofing irons, in lightweight metal castings for toys and fancy goods, in zinc oxide for paints and automobile tyre fillers, in zinc dry-battery cases and alloyed into brasses.

Workers most likely to be affected by zinc fume fever are welders working on galvanised iron in poorly ventilated or unventilated conditions, hot dip galvanisers, zinc smelter workers and zinc oxide and granulated zinc production plant workers. Zinc powder also presents a combustion and explosion hazard.

6.12.2 TOXICOLOGY

Because zinc is an essential metal, occupationally-related poisonings are not numerous. While some poisonings do occur with zinc metal, most arise from zinc compounds. The major route of intake in the workplace is inhalation, with possible subsequent ingestion after clearance from the lung. Zinc is readily absorbed due to its solubility and that of its compounds. The major health consequence of zinc inhalation is metal fume fever, sometimes known as 'brass founder's ague' or just 'zinc chills'. This fever occurs only from exposure to freshly generated fumes of either the metal or zinc oxide. The particles must be sufficiently small to enter into the lung space. The fever is accompanied by increased leucocyte count. Fever onset usually occurs some hours after exposure. A continuously elevated leucocyte count can confer some resistance to a recurrence of fever. There is no indication of chronic health effects from zinc exposure. However, other substances in the fume (e.g. lead, arsenic, cadmium or oxidant gases from welding) may cause chronic illness.

Zinc chloride fumes (resulting from smoke bombs or soldering fluxes) are known to be toxic, causing inflammation and corrosion of lung tissue, and subsequent rapid lung fibrosis. Zinc chloride solutions have a caustic action on the skin. Zinc phosphide used in rat poison is toxic by either inhalation or ingestion.

6.12.3 STANDARDS AND MONITORING

The NOHSC ES-TWA for zinc fume (or respirable zinc oxide) is 5 mg/m^3, with a STEL of 10 mg/m^3 (NOHSC 2006). However, the ACGIH® (2006) recommends a TWA limit of 2 mg/m^3 for zinc oxide as respirable dust, with a STEL of 10 mg/m^3, to prevent metal fume fever. The NOHSC ES-TWA and ACGIH® TLV®-TWA for zinc dust is 10 mg/m^3, while for zinc chloride it is 1 mg/m^3, with a STEL of 2 mg/m^3.

Thus it is necessary to know whether the zinc exposure is to fume or dust. In cases where the zinc is thermally generated (e.g. welding, burning of zinc in a candle furnace, smelting or hot dip galvanising), it is appropriate to assume that it will be finely divided fume. Concentrations up to 10 times the ES-TWA may be achieved during unventilated welding of galvanised steel.

There are no simple, direct methods for assessment of zinc fumes in the field. Monitoring for zinc fume or oxide particulate requires personal sampling with a respirable dust sampler (refer to AS 2985 (Standards Australia 2004a) for details). Monitoring for zinc dust and zinc chloride requires personal sampling with the IOM inhalable dust sampler or equivalent (refer to AS 3640 (Standards Australia 2004b) for details). Measurement requires laboratory assessment, usually by atomic absorption spectroscopy. Sampling in a hot dip galvanising works requires special efforts to protect the sampling head from direct splashes of hot metal, which will burn holes in the filter.

6.12.4 CONTROLS

Good process control by enclosure, adequate LEV or other engineering control should be employed. The metal and oxide fumes are not life threatening, and RPE with a suitable protection factor for metal fumes can often be considered satisfactory when other controls are impractical. For welders working regularly on galvanised steels, airline RPE rather than filter RPE should be considered if work practices consistently place them in the plume of metal fume originating from the welding task. Special RPE products for welding are available from a number of manufacturers. The Welding Technology Institute of Australia supplies a good publication titled *Fume Minimisation Guidelines* (WTIA 1999).

Workers in zinc and zinc product industries should be fully instructed about the nature of health hazards and the control procedures required to prevent exposure.

6.13 NICKEL

6.13.1 USE AND OCCURRENCE

Nickel is obtained from a mixture of ores including sulphides, silicates and laterites. One industrial process (Mond) converts the sulphide to nickel oxide by roasting, followed by conversion to nickel carbonyl by reaction with hydrogen and carbon monoxide and reduction then to pure nickel. Nickel carbonyl may also occur in the chemical, glass and metal plating industries, where it is used as a catalyst in various chemical reactions, in glass plating and in the forming of nickel films and coatings.

Nickel finds use mainly in stainless steels and in a huge number of other nickel alloys with high corrosion and temperature resistance. It is used in nickel-cadmium batteries, nickel plating, monel metal, nickel chemical reaction catalysts, magnetic tapes, coinage, jewellery, and in electronic, electrical and engine parts. Workers are exposed to nickel-containing dusts and fumes during plating and grinding, mining, nickel refining, and in steel plants, foundries and other metal industries. Nickel exposure can also arise from welding of metals containing nickel.

6.13.2 TOXICOLOGY

Nickel exerts two major workplace-related health effects. The first is nickel itch or nickel eczema on the arms of those whose skin is exposed to nickel (e.g. platers). The itch may spread to the face and other parts of the body, constituting an allergic response. Workers so sensitised may not be able to return to this kind of work. Nickel-plated watches, jewellery and earrings may likewise cause an allergic reaction on the skin, produced by sweat in contact with the metal. While nickel can sensitise by direct skin contact, there is good evidence that it can also act as a skin sensitiser after ingestion.

Inhalation of nickel carbonyl can result in acute symptoms of headache, dizziness and vomiting, followed by chest pain, dry cough, shortness of breath and extreme weakness, depending on the exposure. Nickel carbonyl causes haemorrhagic pneumonia. Most of the inhaled nickel ends up in the brain and lung. The process of nickel roasting produces nickel fumes that are considered to be carcinogenic. Some organisations, such as NIOSH (1994), consider nickel carbonyl to be a potential occupational carcinogen, while others do not.

6.13.3 STANDARDS AND MONITORING

There are a number of NOHSC ES-TWAs for nickel compounds, depending on the form of the nickel. The ACGIH® (2006) recommends some different values, as shown in Table 6.2. Nickel carbonate, nickel sulphide and nickel oxide are insoluble compounds of nickel, whereas nickel chloride, nickel sulphate and nickel nitrate are soluble compounds.

Table 6.2 Exposure standards for nickel and its compounds

Nickel compound	NOHSC ES-TWA	ACGIH® TLV®-TWA
nickel metal	1.0 mg/m³	1.5 mg/m³
soluble compounds of nickel	0.1 mg/m³	0.1 mg/m³
nickel carbonyl	0.05 ppm or 0.12 mg/m³	0.05 ppm
nickel subsulphide	1.0 mg/m³ (Category 1 carcinogen)	0.1 mg/m³ (A1 carcinogen)
insoluble compounds as Ni	—	0.2 mg/m³ (A1 carcinogen)

Source: NOHSC (2006) and ACGIH® (2006)

Indicator stain tubes are available for direct in-field measurement of nickel carbonyl in air, though the method is not particularly sensitive. Better sensitivity and precision in the assessment of inorganic nickel in workplace air is obtained by methods such as MDHS 42/2 (HSE 1996c) or NIOSH method 7300 (NIOSH 1994). As with other metals, the dust or fumes are collected on a filter, dissolved by acid and measured by atomic absorption spectroscopy or inductively coupled argon plasma (ICP).

6.13.4 CONTROLS

Because of the irritation and carcinogenic effects of some nickel dusts and aerosols, process control by enclosure or LEV is mandatory. Workers in nickel electroplating should have skin protection against nickel salts and access to adequate washing facilities in case of skin splashes.

Refining processes involving nickel carbonyl must be completely enclosed, preventing any exposure. Only air-supplied RPE is suitable for entry into any area of plant where nickel carbonyl is processed.

Workers handling any nickel metal, its salts or nickel-containing compounds should be instructed in the hazards, particularly the need to be aware of skin conditions. Workers also require instruction in use of controls appropriate to the potential exposure.

6.14 MINOR METALS OF WORKPLACE CONCERN

The preceding sections have dealt with the more common hazardous metals the H&S practitioner is likely to encounter, but there are some others. They are classed as metals of minor significance in terms of their use and occurrence, not because of their toxicology, which may be both complex and fascinating. Their classification as 'minor' also stems from the fact that they are seldom the subjects of extensive workplace health or hygiene investigations.

For example, boron is a toxic metalloid, but its use as a high-energy neutron shield in nuclear reactors is of little consequence to the average H&S practitioner, as there are few reactors operating in Australasia. On the other hand, compounds of boron find wide use in ceramic glazes, fireproofing materials, low-grade insecticides, organic chemical synthesis, printing and painting. So there may well be good reasons to consider these materials as having something other than 'minor' status.

For H&S practitioners seeking more extensive information on the metals of minor significance, it will be necessary to consult some of the references in the further reading suggested in Section 6.16.

Details on sampling procedures for these metals are not presented here, but the NIOSH *Manual of Analytical Methods* (1994) covers most of them. The H&S practitioner should contact a specialist hygiene laboratory if measurement for these metals is required. There are no simple in-field techniques available to the H&S practitioner for assessing any of them.

6.14.1 ALUMINIUM

Aluminium is a relative newcomer to the family of commercial metals. In its mineral form, bauxite, aluminium is the most abundant metal in Earth's crust. Mined bauxite is refined into alumina (aluminium oxide) using a chemical refining process (Bayer), whereby finely ground bauxite is digested in a hot caustic soda solution, then clarified, precipitated and calcined. The alumina is then smelted into aluminium using electrochemical reduction, whereby the alumina is dissolved in molten cryolite in cells through which a direct electrical current is passed via carbon cathodes and anodes. The molten metal formed in each cell is drawn off at regular intervals for casting into various shapes. Aluminium is often alloyed with small amounts of copper, magnesium, silicon, manganese and other elements to impart a variety of useful properties.

Aluminium oxide is used as an abrasive, in refractory material and for electronic applications. The uses of aluminium are numerous: automobile engines, shipbuilding, aircraft manufacture, home products such as doors, window frames, roofing and insulation, electrical wire and transmission cable, packaging material such as aluminium foil, drink cans and wrap, aluminium coatings for telescope mirrors, and to make decorative paper, packages and toys. Aluminium compounds and materials also have a wide variety of uses in the production of glass, ceramics, rubber, wood preservatives and pharmaceuticals, and in waterproofing textiles. Salts of aluminium include alum, which is used in water treatment, and natural aluminium minerals (e.g. bentonite and zeolite), which are used in water purification, sugar refining, brewing and the paper industry.

Aluminium metal readily oxidises to provide a protective aluminium oxide layer against further ordinary corrosion. Powder and flake aluminium are flammable and can form explosive mixtures in air, especially when treated to reduce surface oxidation (e.g. pyro powders). Toxic effects of aluminium are minimal, with exposure standards set to minimise the potential for irritation of the respiratory tract. NOHSC (2006) and ACGIH® (2006) have air exposure standards of 10 mg/m^3 for aluminium metal dust and oxide, 5 mg/m^3 for aluminium welding fumes, and 2 mg/m^3 for soluble salts. There appears to be no serious adverse effect on respiratory health associated with exposure to bauxite in present day open-cut bauxite mines. There is a belief among the general public that aluminium plays some role in Alzheimer's disease, although current research findings do not support this notion. Of more importance for those working in the aluminium electrolytic smelting industry is the potential for a condition known as 'potroom asthma', characterised by cough with dyspnoea, wheezing and chest tightness, usually occurring within the first year of exposure to potroom fumes. While peak concentrations of fluoride in air have been implicated as a causative agent, the actual cause of this asthma is yet to be clearly defined. For those working in aluminium smelters, the production of carbon cathodes and anodes can cause exposure to polycyclic aromatic hydrocarbons (PAHs) from coal tar pitch volatiles (CTPVs). PAHs are carcinogenic, hence of primary concern.

General control procedures for smelting aluminium should principally be aimed at preventing potroom fumes and CTPVs from entering the workplace atmosphere. Expert opinion and advice is needed in order to assess exposures in an aluminium smelter.

6.14.2 ANTIMONY

Metallic antimony finds use in alloys with lead (e.g. battery grids), in cable sheaths, pewter, ammunitions and some solders. Salts of antimony find use in paints, rubber, glass and ceramics. One regular application of antimony trioxide is as a fire retardant used in the manufacture of weatherproofing/insulation membranes used in housing construction. Toxic effects of antimony resemble those of arsenic, with irritation of mucous membranes, gastrointestinal effects, sores in the mouth and skin lesions. The hydride of antimony, stibine, is an extremely toxic haemolytic agent. Antimony trisulphide is also very toxic and reportedly can cause heart failure. This effect on cardiac muscle may extend to other antimony compounds as well.

Its use in lead-acid battery grids leads to the small possibility of stibine production during battery charging. Good ventilation procedures should be followed, particularly in large battery facilities.

Generally, however, antimony does not find significant use in industry. The NOHSC (2006) ES-TWA is 0.5 mg/m^3 for all forms, but note that the production process for antimony trioxide is suspected of being carcinogenic.

General control procedures for working with antimony should be aimed at preventing antimony compounds from entering the workplace atmosphere. Expert opinion and advice should be sought if antimony exposure is a possibility.

6.14.3 BERYLLIUM

Beryllium finds its principal use as an alloying agent in steel, copper, magnesium and aluminium. Beryllium oxide is also a component of ceramics. An old use as a phosphor in fluorescent tubes has long since been abandoned. Major use today is in the nuclear industry, aerospace products and high-stress low-strain products.

Beryllium is cited by the ACGIH® (2006) as a confirmed human carcinogen, causing lung cancer. Mining of the beryl ore is not associated with lung disease. Beryllium poisoning is related to the very toxic effects of beryllium dust, which affects a number of organs. Delayed effects from material deposited in the body can occur. Exposure to beryllium results in beryllium sensitisation, or development of a beryllium-specific, cell-mediated immune response in 2–19 per cent of exposed individuals. Sensitisation usually precedes the development of chronic beryllium disease, or berylliosis, characterised by a Type IV, delayed hypersensitivity, cell mediated immunity. Relatively small amounts of inhaled material can induce acute effects. Expert diagnostic opinion, with particular emphasis on complete occupational history, is extremely important in establishing beryllium-induced disease. Medical control in beryllium-using industries rests mostly on regular health surveillance, including chest X-rays.

The NOHSC (2006) ES-TWA for beryllium is very stringent, at 0.002 mg/m^3. Note that the ACGIH® (2006) has a notice of intent to lower this even further, to 0.0002 mg/m^3. Thus any grinding, polishing or machining process on beryllium-containing metals or ceramics should be considered very carefully. Good occupational hygiene practice will be required to keep the risk of working with beryllium at an acceptable level. Industrial or research operations using beryllium should be carefully assessed. See MDHS 29/2 (HSE 1996b) for air monitoring.

6.14.4 BORON

Boron is an essential element for plants and animals, including humans. Boron compounds are widely used in applications such as household cleaning products (e.g. detergents and bleaches) through to boron fibre technology. Borax and boric acid are used in smelting and in glazes for ceramic ware, for production of glass and glass-related products (e.g. insulation and textile fibreglass, Pyrex®), and borax is still used in fireproofing of pulped cellulose insulation, low-activity insecticide mixtures and tanning. These compounds do not pose significant hazards in normal use and consequently the exposure standard is from 1 to 10 mg/m^3 (TWA), depending on the type of boron compound. Occupational hygiene practice needs to ensure that neither inhalation nor ingestion of dusts can occur.

Several other boron compounds, including boron trifluoride and boron trichloride, find use in chemical synthesis and organic chemical reactions.

There are several boron hydrides (e.g. diborane, pentaborane, decaborane and others), which are highly toxic. They are used mainly in high-energy rocket 'zip' fuels and in pharmaceutical and rubber vulcanising. They are very irritating to skin and mucous membranes and produce headache, chills, dizziness and weakness. These compounds also have extreme fire and explosion hazard risks. Good occupational hygiene practice (engineering control, personal protective equipment) is required to provide adequate control of these substances.

6.14.5 COBALT

Cobalt, being a relatively rare element, is also relatively rare in the workplace. The metal finds use in Al-Ni-Co permanent magnets, as a binder in hard metal cutting tools, in some electrical alloys and in some dental metal alloys. Some cobalt salts, such as cobalt blue and cobaltous chloride, have been used in glass and ceramic enamels for colouring. Cobalt is an essential element in the formation of vitamin B_{12}.

Sometimes associated with 'hard metal disease', cobalt metal workers have developed a pulmonary disease, though exposure to other materials might be implicated also. The effects of cobalt poisoning include diarrhoea, loss of appetite, hypothermia and possible death. Inhalation of cobalt dust can cause pulmonary oedema in animals and so should be avoided. An allergic dermatitis is also recorded in some workers, resulting from exposure to minute amounts. This type of sensitive allergy has been seen in the building, metalwork, pottery, leather and textile industries.

Inhalation exposure should be limited, preferably by isolation, LEV or other engineering controls. This is particularly important for grinding operations that produce fine dust. Control of airborne dusts should also reduce the need for skin protection. Additional skin protection, including barrier creams, may prove necessary in difficult-to-control situations. RPE must be of a high standard for mechanically-generated dusts, preferably air-line respirator or high efficiency filter respirator, dependent on the protection factor required.

The NOHSC ES-TWA for cobalt metal and compounds is 0.05 mg/m^3 (NOHSC 2006). The ACGIH® (2006) has recommended a lower standard, 0.02 mg/m^3.

6.14.6 COPPER

Another essential element, copper finds common use in electrical service, alloys of brass, bronze or monel, plumbing services and cookware. Copper is also used in insecticides and as an algicide and a bactericide, and in electroplating. Industrial exposure to copper fume is not common—copper melts at about 2350°C—though the fume can give rise to a metal fume fever similar to zinc fume fever. Copper salts, copper carbonate and sulphate are all relatively safe to use, provided proper precautions are taken to prevent inhalation or accidental ingestion of dusts. Ingestion of copper has occurred accidentally when suitably acidic foodstuffs have been in contact with copper vessels (e.g. fruit juice, moonshine liquor from copper stills). Industrial copper exposure presents no significant problem, other than for workers with the rare occurrence of Wilson's disease, a genetic inability to excrete excess copper.

The NOHSC ES-TWAs for copper fume and copper dusts are 0.2 mg/m^3 and 1 mg/m^3 respectively (NOHSC 2006). Note that the ACGIH® (2006) has a notice of intent for a lower standard of 0.1 mg/m^3 for inhalable copper metal and oxides to prevent respiratory tract irritation, and 0.05 mg/m^3 for respirable soluble copper salts to prevent potential reduced ability to resist lung infections.

6.14.7 MANGANESE

Manganese finds its major use in steel making, but it is also used in aluminium alloy and cast iron production, in alkaline manganese dry batteries, as manganese dioxide for brick colouring, as an oxidising agent in dyes and chemicals, as a catalyst, as manganates and permanganates for disinfecting and bleaching, and as a fungicide. Manganese mining and smelting of the ore (pyrolusite) create the greatest exposure hazards. Subsequent environmental contamination around smelters also can occur. Other small exposures occur in welding with manganese-containing rods, and (dark) paint pigments. The organic manganese compound, methylcyclopentadienyl manganese tricarbonyl (MMT), has been used as an additive to increase octane rating in petrol.

Manganese is an essential trace element, but in excess amounts can cause neurological disorders involving the central nervous system. The syndrome (manganism) results in symptoms ranging from apathy, anorexia and mental excitement, to speech disturbance, clumsiness and a stone-faced appearance. In the established phase of the disease staggering gait, muscular rigidity (e.g. finger or hand deformation), spasmodic laughter or tremors may occur. Manganese-poisoning victims may be cripplingly debilitated but otherwise well. There was concern by some that MMT might contribute to neurological effects, as has occurred due to tetraethyl lead in petrol, but this has not eventuated.

Metal fume fever can follow inhalation of fine manganese fume and a manganese-induced pneumonia can occur. Manganese poisoning has also been associated with lung function decrease and is implicated in reduced fertility of male workers.

Prevention of manganese-related disease is dependent mostly on preventing inhalation of manganese-containing dusts and fumes. Manganese can also be accidentally ingested. LEV and other engineering controls should be adequate to maintain exposures within the NOHSC (2006) ES-TWA of 1 mg/m^3 for manganese fume, dust and compounds. The ACGIH® (2006) recommendation is 0.2 mg/m^3, to protect against central nervous system effects. Use of RPE, subject to achievement of appropriate protection factors, could be appropriate, provided that the work and task factors permit wearing of such RPE.

Medical supervision of those exposed occupationally to manganese dusts is advisable. Manganism exhibits three distinct phases, so detection of any slight neurological abnormality may be beneficial in terms of removing exposed workers before symptoms worsen.

6.14.8 SELENIUM

Selenium is a non-metallic element that can occur in a metal-like form, obtained as a by-product of refining copper (and sometimes zinc) ore, hence exposure to fume can occur during the smelting and refining of these ores. Some of its forms are volatile, hence more difficult to contain. Occupational exposure to selenium is primarily via inhalation, although in some cases it can be by direct skin contact. It is used in the manufacture of glass, pigments, ceramics and semiconductors; in xerography, rectifiers, steel, photography, photoelectric cells, catalysts and in rubber vulcanising. Selenium compounds are also used in the treatment of a number of animal and human diseases—it is well known in anti-dandruff shampoos. It is an essential trace element for animals and humans, but can bio-concentrate to toxic levels in both, causing selenosis.

The acute toxicities of the inorganic selenium compounds vary greatly, from those of the highly poisonous hydrogen selenide, selenium oxychloride, selenium dioxide and selenium hexafluoride, to those of the element and sulphides, which are considered of much lower toxicity. Selenium dust, selenium dioxide and hydrogen selenide are more likely to be encountered in the workplace. The chronic effects of nearly all forms of selenium in humans appear to be similar: depression, languor, nervousness, dermatitis, upset stomach, giddiness, garlic odour of the breath and sweat, excess dental caries, and in extreme cases loss of fingernails and hair. Most knowledge of selenium's toxic effects is derived from clinical toxicology and the incidence of selenium poisoning as a result of ingestion of seleniferous grains and other foodstuffs; there have been no reports of disabling chronic disease or death from industrial exposures. The NOHSC (2006) ES-TWA standard is 0.1 mg/m^3 for selenium compounds (excluding hydrogen selenide), which is half that of the ACGIH® (2006) (0.2 mg/m^3), to minimise eye and upper respiratory tract irritation, as well as systemic effects such as headache, garlic odour of breath, skin rashes, etcetera. The ES-TWA standard for hydrogen selenide is 0.05 ppm or 0.16 mg/m^3.

General control procedures for working with selenium should be aimed at preventing selenium compounds from entering the workplace atmosphere. Expert opinion and advice should be sought if selenium is encountered in a workplace.

6.14.9 THALLIUM

This metal was once widely used in the preparation of salts for rodenticides, because it is undetectable by taste or smell, but is no longer readily available in developed countries. Thallium is also used in special optical lenses for scientific equipment (infrared cells), glass tinting, the semiconductor industry and photoelectric cells. It is also alloyed with lead, zinc, silver and antimony to enhance resistance to corrosion. A rare use of thallium is in Clerici's solution, thallium mallonate, which has a high specific gravity. This is used in heavy mineral test separations in the mineral sands industry. Thallium may also be encountered in the production of cement and in the handling of pyrites and flue dusts.

Most deaths due to thallium are from either accidental poisonings (poisoned grain mixed in with grain to be milled), or deliberate (suicidal or homicidal) non-occupational poisonings. Thallium is also absorbed through the skin. In severe poisonings, symptoms include swelling, joint pain, vomiting, mental confusion and loss of hair.

Industrial poisonings during the preparation of the thallium salts have been milder, due mostly to the care taken in handling thallium salts, but they are usually longer term than the acute deliberate poisonings. Occupational history is extremely important in diagnosis.

The NOHSC (2006) ES-TWA standard is 0.1 mg/m^3, the same as the ACGIH® (2006) one. Biological monitoring of urine may be useful to consider for those regularly involved in the preparation of thallium compounds.

If thallium must be used, isolation of processes is mandatory, with strict precautions to prevent dispersal of airborne dusts in the workplace (LEV) and skin contact (personal protective equipment). Hand-washing facilities and separated eating facilities are mandatory, eating and smoking in the workplace must be prohibited, and the wearing of work clothes to and from home should be forbidden.

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7. Gases and vapours

Noel Tresider FAIOH

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7.1 INTRODUCTION

Some gases and vapours are vital to life on this planet. The oxygen in the air we breathe, the water vapour humidifying the air and the carbon dioxide exhaled as a metabolic by-product are all essential to our existence. But in the workplace, the air we breathe can be contaminated with various gases and vapours which may threaten our health, or even our lives. Workplace and even domestic processes can involve many hazardous gases or vapours.

In this chapter, we examine gases and vapours for their workplace health and hygiene significance. There are an enormous number which are potential workplace contaminants, and not all can be covered here. The toxicological information presented is restricted to materials regularly encountered. For H&S practitioners with specific workplace issues related to the toxicology of rarer gases and vapours, reference to a more advanced text will be necessary. It is also recommended that other resources, such as websites with regulatory information, be consulted for recent developments.

Gas and vapour monitoring is addressed in more detail, and the differences between short- and long-term monitoring are explained. While many H&S practitioners may be prevented from sampling through lack of proper instrumentation, they should still understand the basics of monitoring and, in particular, why it is done. Some may prefer to leave monitoring to consultants or hygiene laboratories. Knowledge of sampling techniques is invaluable in interpreting results and in demonstrating to a workplace Health and Safety Inspector that you have provided suitable and sufficient assessment of hazardous substances.

The special case of confined spaces, and the significance of monitoring gas and vapours in these environments, is also examined.

Lastly, we look at some specific examples of hazards created by gases or vapours and how we control them. These hardly scratch the surface of this enormous field of study, but they do serve to illustrate the principles and techniques commonly encountered.

7.2 GASES

True gases exist in the vapour phase at normal temperature and pressure. Many can be stored as pressurised liquids until vaporised for use. If not controlled, the gas may enter and contaminate the workplace breathing air. Some examples of workplace contamination arising from process gases are:

- chlorine from water treatment plants
- nitrous oxide (laughing gas) in anaesthesia
- ammonia from refrigeration plants
- oxygen from liquid oxygen sources
- hydrogen cyanide from grain fumigation
- ethylene oxide from sterilisation machines in hospitals.

Other gaseous contaminants may arise as by-products of industrial processes. Typically this is where some sort of chemical reaction has taken place, or where the gas is produced in the breakdown of a complex chemical, for example:

- carbon monoxide from incomplete burning of natural gas in ovens and kilns
- oxides of nitrogen from diesel exhausts
- ozone from photocopying or some electric arc welding machines
- formaldehyde off-gassing from particle board
- hydrogen sulphide from sewers and waste water treatment plants
- oxygen depletion in confined spaces due to anaerobic or oxidation reactions (rusting).

7.3 VAPOURS

Vapours, on the other hand, arise from evaporation of materials which usually exist as liquids at room temperature in the workplace. Thousands of organic chemicals used as solvents, adhesives, paints, chemical reactants, catalysts, sterilants or processing aids produce vapours through natural evaporation, heating or spraying.

Organic chemicals in the form of solvents are by far the largest source of vapours in workplaces. These organic compounds are often chosen as solvents because of two special abilities—they will dissolve a material and they will readily evaporate into the atmosphere. This last property leads to many of the problems of exposure. Some typical examples of organic solvents are acetone, chloroform, ethanol, chlorofluorocarbons (CFCs), hexane, perchlorethylene and xylene. You will find organic solvent-based chemicals in the factory, the farm, the office and the home.

A few materials actually sublime, that is, convert from the solid directly to the vapour. Examples include naphthalene (moth balls) and paradichlorobenzene (deodorant).

7.4 WARNING SIGNS AND INDICATORS

7.4.1 ODOUR

Gases and vapours are mostly invisible. Many have strong and characteristic odours which give warning of their presence in the workplace, but others have no warning odour (e.g. carbon monoxide), and with still others, harmful health effects may be caused at concentrations well below the odour threshold. With some substances, warning odorants are added to prevent inadvertent exposure and/or to detect the presence of a gas. For example, the odorant ethyl mercaptan is used in liquified petroleum gas (LPG) and natural gas supplies. Lastly, there is great variation between individuals in their ability to detect odours, and even for the same person it may vary from day to day. For example, the range of odour detection of methyl ethyl ketone (MEK) lies between 2 and 85 ppm. In other words, while odour can be useful in detection there are a number of limitations to its use. Odour is often a good warning indicator for bacterial decay. However, odour cannot easily indicate the degree of exposure; for some gases (e.g. hydrogen sulphide), higher concentrations cause olfactory fatigue and the contaminant can no longer be smelt even when the concentration of the gas may be at lethal levels. Odour is often mistakenly associated with causing harm. Odour is an **unreliable indicator of harmful conditions**, and is not a measure of toxicity. Some gases are deadly and do not smell, others are odorous at very low levels far below that which will cause harm—they just smell unpleasant.

For many volatile materials, the odour threshold may be one-tenth to one-thousandth of the exposure standard. Table 7.1 shows the relation between approximate odour thresholds and exposure standards for a number of common workplace gases and organic vapours.

Table 7.1 Comparison of odour thresholds and exposure standards for some commonly occurring workplace gases and vapours

Substance	Odour threshold (approximate) ppm*	Australian exposure standard ppm
Acetone	62	500
Ammonia	17	25
Ethylene oxide	420	1
Hydrogen sulphide	0.0002	10
MEK	16	150
Ozone	0.01	0.1
Styrene (monomer)	0.15	50
Toluene	1.6	50
1,1,1 Trichloroethane	82	100
Xylene	20	80

* American Industrial Hygiene Association (1989)

Although odour cannot be relied on as a means of measurement in the workplace, it is still a very useful property. Workers are equipped with a very sensitive odour detector, the nose. In fact, the nose is often much more sensitive than analytical devices to certain chemicals. But odours are easily masked, and the nose is very poor at distinguishing mixtures of materials.

7.4.2 IRRITATION

Some gases and vapours may reveal their presence by various irritating effects:

- respiratory irritation, coughing, asthma
- lachrymatory action on the eye (tearing)
- cloudy vision (at high concentrations) or other visual disturbances
- acidic taste
- metallic taste (organo-metallic compounds).

Acidic gases, including chlorine and sulphur dioxide, may be evident because of respiratory irritation rather than smell. In some workers, formaldehyde may cause eye irritation before it can be detected by smell. Investigation of the workplace may reveal a range of processes which produce gases or vapours, and the H&S practitioner will need to distinguish between those which have reliable warning properties and those which do not.

7.5 OCCUPATIONAL HEALTH ASPECTS OF GASES AND VAPOURS

For health and safety purposes, gases and vapours can be classified into three groups:

- irritants
- asphyxiants
- miscellaneous.

Both irritants and asphyxiants tend to give rise to relatively acute responses, leading to rapidly observed effects. The miscellaneous effects include both acute and chronic effects.

7.5.1 IRRITANT GASES AND VAPOURS

These cause inflammation of the tissues which are exposed to them. Symptoms of exposure can range from mild irritation of the mucous membranes (eyes, nose and throat) to severe damage of the lung (e.g. by chlorine, phosgene, formaldehyde and nitrogen dioxide).

7.5.2 ASPHYXIANTS

Asphyxiant gases fall into two groups:

- **Simple asphyxiants**, which have little direct physical effect but merely displace the oxygen from air. Confined spaces into which workers may have to enter may have a low oxygen level due to displacement by other gases, including methane, carbon dioxide, helium, nitrogen and sulphur hexafluoride.
- **Chemical asphyxiants**, which are gases that interfere with the transport of oxygen by the blood or the use of oxygen by tissues. For example, low concentrations of carbon monoxide or hydrogen cyanide can be very toxic.

7.5.3 MISCELLANEOUS GASES AND VAPOURS

Many gases and nearly all vapours from solvents fall into the miscellaneous category. Effects include acute effects, for example on the central nervous system (CNS), and chronic toxic effects in many different organs of the body. Some typical examples of miscellaneous effects caused by gases and vapours which may occur in industrial workplaces are shown in Table 7.2.

Table 7.2 Gas or vapour hazards demonstrating different health effects

Gas or vapour	Health effect
Helium	vocal changes
Nitrous oxide	analgesia
Oxygen (excess)	pulmonary inflammation, lung oedema
Oxygen (deficiency)	brain disturbance, CNS effects
Methyl bromide	cardiac effects
Vinyl chloride	angiosarcoma of the liver
n-Hexane	peripheral nerve neuropathy
Nitroglycerine	vasodilator decreasing blood pressure
Toluene	headache, confusion, loss of memory
Ethyl glycol monoethyl ether	foetotoxic effects
Trichlorethylene	psychoactive effects
Fluorocarbons	cardiac arrythmias
Benzene	leukaemia
Carbon disulphide	cardiac disease
Coal tar pitch volatiles	skin sensitisation, lung cancer

7.6 UNDERSTANDING EXPOSURE MEASUREMENT IN THE WORKPLACE

We will now address the problem of how to measure gases and vapours in the workplace.

Firstly, the H&S practitioner needs to understand what exposure is occurring in the workplace. While the exposure standards are listed as a single value for an 8-hour average and/or a 15-minute average, in reality the workplace exposure is changing continually throughout the work shift, and it is the summation of these exposures to a particular contaminant that is averaged over the shift time to give the daily exposure of the worker as a single value, which is then compared to the exposure standard for that contaminant. Figure 7.1 shows a typical exposure at a workplace during part of a work shift as the output from a data logger measuring hydrogen sulphide (H_2S) exposure at 1-minute intervals of a worker near the hatch of a tank. The output highlights the changing concentrations which can occur over a work shift. Thus any instantaneous reading from a 'grab sample' will be only one result at one time in a changing environment. (A grab sample is an air sample collected over a short period of time—usually between 1 and 5 minutes.)

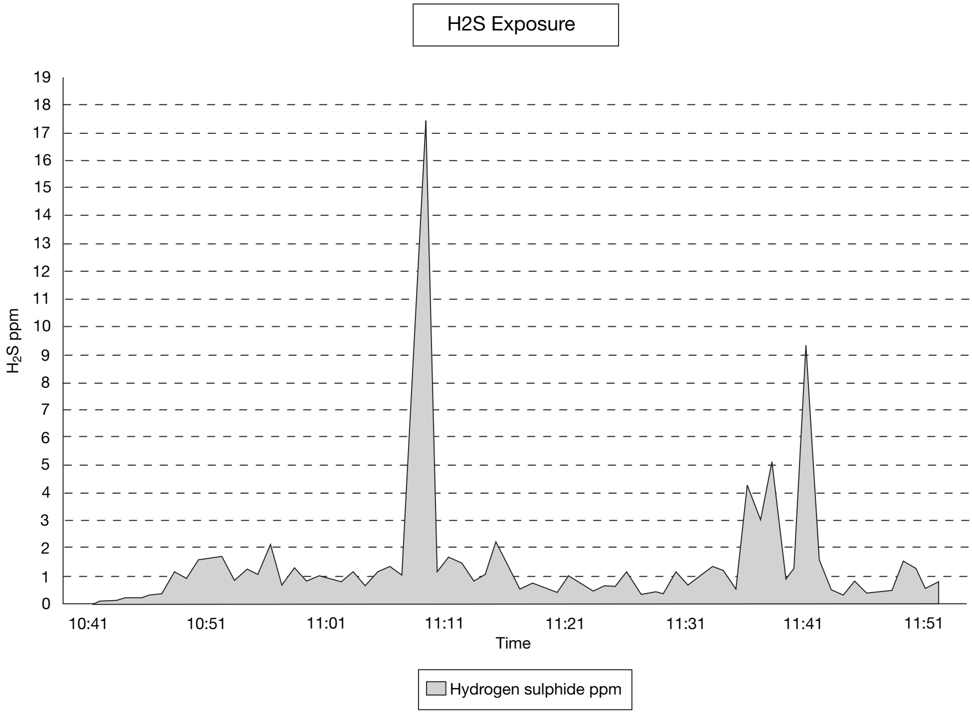

Figure 7.1 Hydrogen sulphide levels at a bitumen tank hatch

In the above case, if no further exposure occurs in the 8-hour shift, then the hydrogen sulphide TWA is only 0.2 ppm, which is well below the exposure standard of 10 ppm. Yet clearly, during one short period, the instantaneous readings were well in excess of this standard.

7.7 MONITORING OF GASES AND VAPOURS

A large number of gases and organic vapours occur in various workplaces, and many different techniques are required to assess them.

Gas and vapour sample collection for monitoring is relatively simple compared to dust sampling. There are no size sampling requirements—monitoring simply requires that the H&S practitioner collects and measures the total concentration in the atmosphere. While some gases and vapours may be dissolved in the moisture of the upper airways, others can reach the alveolar regions of the lung and so may undergo exchange into the bloodstream. While a considerable part of inhaled gas or vapour will be exhaled again, exposure measurement is based on the total amount available for inhalation.

In monitoring of gases and vapours there are two key factors:

- **Identification** What gas (or gases) or vapours are present; in other words, which air contaminants are present?

- **Quantity** How much of that contaminant to which the worker is potentially exposed throughout the work shift is present?

The answers to these questions will determine how the worker's exposure will be measured.

To determine *what* is in the air (identification) requires methods or instruments which can characterise the various contaminants. This can be ascertained by collecting an air sample with subsequent analysis in the laboratory, or by use of direct reading instruments such as portable gas chromatographs, or instruments for specific contaminants such as hydrogen sulphide or carbon monoxide. Determining *how much* contaminant is present in the worker's environment requires monitoring the specific contaminant over a certain time period. This requires either a direct reading monitoring instrument or collection of the contaminant during the work period and subsequent laboratory analysis.

7.8 OPTIONS FOR MONITORING THE WORKPLACE AIR

Several techniques present themselves for gas and vapour monitoring:

- Conventional **monitoring of the workplace air**. More than 98 per cent of all gases and vapours are investigated in this fashion.
- **Monitoring the worker** for uptake of a gas or vapour by examining a biological index for the particular substance. This may be done by measuring excretion of the substance or measuring a metabolite of the inhaled substance.
- **Analysing the air** exhaled by the worker at some time after the end of a work shift.

7.9 MONITORING THE WORKPLACE AIR

For the present, emphasis will be placed on air monitoring because of its simplicity and practical utility. The H&S practitioner will find that quite a large number of regularly occurring gases and vapours can be conveniently measured with modest equipment. As discussed in Chapter 4, Control of Workplace Health Hazards, air monitoring is a requirement when respiratory protection programs are introduced. Two approaches are widely used:

- direct reading instruments for use in the field
- sample collection with subsequent laboratory analysis.

7.10 DIRECT READING INSTRUMENTS

As the name suggests, these devices can provide data on exposures in the field. There are five good reasons why we use direct reading instruments in the field:

- There is no need to await long, often costly, laboratory analyses.
- They can identify high short-term exposures which may lead to acute effects, e.g. facilitate confined space entry.

- Checks can be made on extraction processes and other control procedures, i.e. identifying leaks and major breakdowns.
- They provide some alarm functions for evacuation or remedial action.
- They can provide estimates of longer term exposures if used with correct sampling procedures.

Hundreds of common gas or vapour contaminants require workplace monitoring, and modern chemical and electronic technology has provided a range of instruments to measure many of them. A good number are well within the operational capability of an appropriately trained H&S practitioner.

Here we examine only the instrument types which find regular use in workplace surveillance. Their use may range from occasional to constant, depending on the particular hazard, how often processes change, and how effective the control procedures are.

7.11 DIRECT READING: COLOUR STAIN TUBE ANALYSER

For many gas and vapour monitoring tasks, the most convenient form of testing is to use a stain tube analyser (Figure 7.2 shows the Dräger® Accuro®).

Figure 7.2 Dräger® Accuro® with a selection of detector tubes

A hand-operated bellows or a piston pump draws a known volume of contaminated air through a tube containing a reagent chemical. This chemical undergoes a visible colour change when reacting with the gas or vapour to be measured. The concentration of the airborne contaminant is read directly from graduations printed on the tube, or from evaluation of the intensity of the coloured stain with a standard comparison tube.

Stain tube analysers are low cost devices, and tubes are available for a very wide range of applications. Special expertise to operate the equipment is not required. They are excellent for monitoring *single* known contaminants. Disadvantages include cross-sensitivities to other unknown contaminants, which can lead to false readings. In addition, the tubes often have limited shelf life and are not always available in the range of concentrations required.

Considerable expertise is required to interpret results. Samples collected by this means are grab samples, representing concentrations at particular points in time. The user must think about the particular work task, the way the sample was collected and how to interpret the results in terms of the relevant exposure standard.

H&S practitioners responsible for work areas where gases and vapours constitute a significant part of workplace air contaminants should consider obtaining these useful gas detector tubes. (The kit includes a hand-operated sampling pump and accessories; the appropriate detector tubes need to be specified for the gas/vapour of interest and are purchased separately.) Several brands are available.

7.11.1 LIMITATIONS OF STAIN TUBE DETECTOR SYSTEMS

Detector tube systems should not be used for establishing whether or not a contaminant is present, only for measuring already known contaminants. Common problems include:

- tubes can give false positives from other materials in the workplace which might react with the colour reagents in the tubes
- tubes can give false negatives if the incorrect measuring range is chosen
- tubes can indicate false negatives if the real identity of the contaminant is not known and an incorrect tube is selected.

7.11.2 PRACTICAL INSTRUCTIONS

H&S practitioners intending to purchase and use one of these devices should consult the various manufacturers. Dräger®, MSA® and Kitigawa® produce different designs, including hand bellows, thumb pump and piston types. All manufacturers offer a wide range of tubes, but you will need to choose a measuring range appropriate for your particular workplace and its contaminants. Do not interchange pumps and tubes from different systems, for there is no guarantee that the pumped sample volumes will be identical for each system.

The manufacturers or suppliers should be able to offer training in the use of this equipment, together with appropriate selection of measuring tubes. Dräger® can also supply a personal computer-based monitoring management system for its tube-based measurements, which informs the user on the following:

- which type of stain tube to use for particular contaminants
- which measuring range tube to choose
- how to read the tube

- warnings on any cross-contaminants
- the appropriate exposure standard
- the appropriate respiratory protection required for various levels of contaminant detected.

Similar information may be available from other suppliers.

The following is a brief set of instructions for using a direct reading stain tube system, in this case the Dräger® bellows pump and stain tubes:

1. Select the appropriate tube for the measuring task.
2. Check the sampling pump for leaks or blockages.
3. Consult the manufacturer's instructions for number of pump strokes required and interpretation of readings.
4. Break open both ends of the indicator tube and any centre tube ampoules.
5. Insert tube correctly into pump with gas flow in direction shown by arrow.
6. Squeeze bellows pump immediately to full extent; allow pump to expand to the limit of the chain at the speed determined by the resistance of the tube.
7. Repeat the pump operation (step 6) for the required number of strokes as indicated on the side of the tube or in the manufacturer's instructions.
8. Read the contaminant concentration directly from the graduation shown on the tube.
9. Record the observed contaminant concentration.
10. Note any variations in the colour indicated by the tube. Different colours from those predicted may indicate that another contaminant is present.

Stain tube indicator measuring systems can be supplied with a remote measuring attachment (effectively a long tube). This makes it possible to measure gas or vapour concentrations at various depths in silos, wells, sewers or underground shafts, etcetera. Such measurements may be necessary prior to entry into a confined space with an atmosphere of unknown quality.

7.12 PASSIVE DIRECT INDICATING SAMPLING TUBES

For a limited range of gases and vapours, passive dosimeter sampling tubes (where no pump is required) have been developed. These tubes are placed in the worker's breathing zone (Figure 7.3) and the TWA concentration is read directly from the graduations on the tube at the end of the sampling period, usually a full shift.

7.13 DIRECT READING BADGES

Several specific direct reading badges are now available (e.g. formaldehyde, isocyanates, ethylene oxide). When exposed to contaminating vapours of a specific kind, the badge changes colour to a hue and intensity which is proportional to the average amount of contaminant in the air. To use these badges successfully, the H&S practitioner should be quite certain of the nature of the contaminant to be measured.

Figure 7.3
Personal direct reading passive monitoring tube on an operator's lapel close to the breathing zone

For example, the direct reading badge for isocyanate vapours will not respond to the liquid aerosols generated in spray-painting operations.

Figure *7.4* illustrates a direct reading isocyanate vapour badge and the card reader. The average exposure (e.g. in parts per billion (ppb)-hours) is read directly by matching the colour of the exposed badge against the calibrated readout card. Similar technologies have been extended to instruments (densitometers) which read the colour intensity on a paper tape.

7.14 SPECIFIC DIRECT READING ANALYSERS

There is now quite a wide range of analysers for specific contaminants found in the workplace. Instrumental analysers for many gases such as carbon monoxide, sulphur dioxide, phosphine, carbon dioxide, cyanide, ammonia, flammable gas, hydrogen sulphide, hydrogen, formaldehyde and chlorofluorocarbons, as well as for oxygen, are widely used. These instruments work on various principles of electrochemistry, infrared spectrometry, photo-ionisation or direct reading paper tape colorimetry. Figure *7.5* shows a carbon monoxide monitor in use to sample a work area.

Instrument analysers are made for fixed location as well as for portable use. Fixed location instruments are typically found in processing plants where fugitive gases and

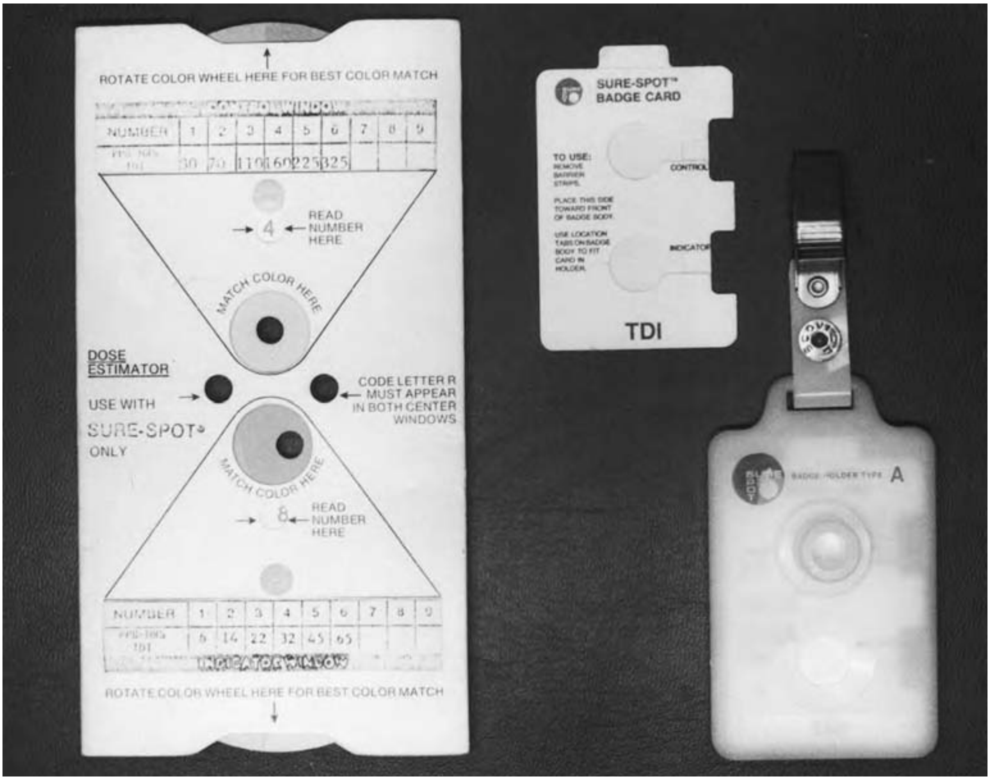

Figure 7.4 Direct reading badge and card reader for TDI (toluene diisocyanate) vapour

Figure 7.5 Worker being monitored using various direct reading monitoring devices

vapours can pose potential hazards to unprotected workers. They are often installed in parking stations to monitor and control the ventilation system used to remove carbon monoxide and other exhaust gases. Instruments for personal use are often fitted with visible and audible alarms set at or just below the appropriate exposure standard.

Internal data logging facilities can be added to those instruments which have a continuous monitoring facility. Data logging permits calculation of TWA concentrations, identification of any peak exposure and identification of any exposure pattern in the workplace (as illustrated in Figure 7.1). Modems and computer software programs are usually available from the instrument manufacturers to link the data loggers to most personal computers.

Figures 7.6 and 7.7a and b show three instruments that are useful for direct field measurements. Modern direct reading analysers are easy to use, but their application needs to be properly considered.

Figure 7.6 Photovac® PetroPro®

Figure 7.7a
MiniRAE®

Figure 7.7b
Photovac® 2020

Direct reading analysers usually cost in the thousands of dollars range, so they require frequent use to justify their purchase. Many manufacturers provide models with three or four separate sensors in the one instrument package. For example, the oxygen/explosive gas/hydrogen sulphide type is indispensable for confined space entry (e.g. sewers, silos, silage pits and mines) and is particularly useful for other confined space applications (discussed in Section 7.21). Figure 7.8a and b shows two multi-sensor types. If you consider using one of these instruments, bear in mind:

- the need for regular calibration checks
- servicing requirements (electrochemical cells have limited lives, from 6 to 12 months)
- use is strictly limited to particular contaminants
- the possibility for cross-contamination or sensor poisoning
- the high initial cost, although some instruments can be hired.

Figure 7.8a MultiRAE®

Figure 7.8b Dräger® X-AM 7000®

7.15 GENERAL PURPOSE DIRECT READING ANALYSERS

Several different devices are now available for general purpose gas and vapour detection:

- portable gas chromatographs (see Figure 7.9)
- opto-acoustic gas analysers
- infrared analysers.

These very versatile instruments provide occupational hygienists with great sensitivity and selectivity in monitoring for workplace organic vapours, but are not generally recommended for use by H&S practitioners. If your workplace encounters some dozens of organic vapours (e.g. a chemical manufacturing plant, solvent reprocessing plant, large manufacturing process plant), general purpose devices can provide an efficient and rapid means of process surveillance.

Figure 7.9
Voyager® portable gas chromatograph

Another kind of general testing instrument, the photo-ionisation detector (see Figure 7.10) finds use with a wide range of organic vapours. This device is not specifically designed for individual contaminants, but can be calibrated for known substances and is useful for single-contaminant situations. It has excellent sensitivity for many compounds encountered in the workplace, particularly chlorinated fluorocarbons (CFCs) used in refrigeration plants and chlorinated solvents.

Recent advances in instrumentation in photo-ionisation detection equipment now allow these instruments to be used as personal monitors, for example the ToxiRAE® PGM30® shown in Figure 7.10.

Figure 7.10 ToxiRAE® PGM30® photo-ionisation detector

7.16 SAMPLE COLLECTION TECHNIQUES

Conventional sample collecting techniques may need to be applied where:

- time weighted average concentrations are required, or
- no direct reading instruments are available.

Chapter 2, Occupational Health, Basic Toxicology and Epidemiology, indicated that much of our knowledge of the long-term hazards from exposure to hazardous gases and vapours is based on average long-term exposures in the workplace. While a few short-term high or peak exposures may lead to irritation, narcotic effects and feelings of nausea, giddiness and so on, it is often the long-term lower exposures which lead to sensitivity, organ damage, neurotoxic effects and cancer. For this reason, we may need to estimate exposure over longer periods.

Measuring exposure to chemicals implies that there is an exposure standard which can be used to determine compliance or otherwise. While exposure standards vary slightly from country to country, the method of measurement does not. Reference should be made to the regulated standards in your country. If none exists for a particular chemical, then most professionals use either the American Conference of Governmental Industrial Hygienists (ACGIH®) TLVs® (ACGIH® 2006) or the UK's Health and Safety Executive (HSE) exposure standards as guidelines.

To comply with these standards, time weighted average exposure measurements are generally required, principally as personal samples.

Four different techniques are regularly used. In order of practical importance they are:

1. Collection of gas or vapour by pumping the contaminated air through a small sampling tube filled with a suitable absorbent.
2. Passive adsorption of the contaminating gas or vapour onto a badge or tube dosimeter worn on the lapel of the worker.
3. Collection of the contaminating gas or vapour by bubbling it through a suitable liquid in a liquid impinger.
4. Passing the gas or vapour through a filter impregnated with a material which reacts with the contaminant.

7.16.1 TUBE SAMPLING

This is the most commonly employed approach for reliable workplace vapour monitoring. Sampling techniques for monitoring and interpretation are to be found in AS 2986.1 *Workplace Air Quality—Sampling and Analysis of Volatile Organic Compounds by Solvent Desorption/Gas Chromatography—Pumped sampling method* (Standards Australia 2003a). Other methods which can be used are the US NIOSH Test Methods, US OSHA Method, or the UK HSE MDHS (Method of Determination of Hazardous Substances).

Adsorbents used in the sampling tubes may be activated charcoal, silica gel, or a number of special chemicals. A small sampling pump is set at a constant flow, anywhere between 20 and 250 ml/min, and draws the contaminated air through the adsorbent. Sampled tubes are usually stable for periods between days to weeks, if properly capped and stored in a refrigerator.

Sampled tubes have to be assessed in a chemical laboratory. The contaminant can be stripped from the adsorbent by:

- action of a powerful solvent such as carbon disulphide
- thermal desorption in a hot furnace (this requires special tubes).

The concentration of contaminant in the air is measured by either gas chromatography or high performance liquid chromatography. These measurement facilities are generally available only in commercial, research or government laboratories. The sampling, however, is available to any H&S practitioner who has the necessary low-flow sampling pumps and who can apply the appropriate Australian Standard®, NIOSH, OSHA or HSE method.

Where a government inspector is auditing risk assessment procedures under one of the various Australian state Hazardous Substance Regulations, the employer or the H&S practitioner may be requested to provide time weighted average (TWA) contaminant concentrations for various workers. Use of a pumped sample tube which is analysed by a competent laboratory is generally an acceptable method of meeting this need.

There are some limitations to this method:

- Most permanent gases cannot easily be determined by such methods (for hydrocarbons, only butanes and heavier can be measured by this method). The limitations of the analysis should be discussed with the testing laboratory.
- Breakthrough of contaminants may occur with excessive flowrates or sample volumes. (This means that some of the contaminant has passed through the sample tube and not been collected, resulting in underestimation of the worker's exposure.)

Breakthrough can be determined by using a tube with two segments, a normal trapping segment and a back-up segment. Total volume of sampled air should be kept low enough that breakthrough is prevented or at least minimised. These sampling tubes again come in a wide variety of adsorbents and with different weights of adsorbent packing. The typical tube is the standard NIOSH tube, which has a 100 mg packing with a 50 mg back-up section. For higher volumes the 1000 mg 'jumbo' sampling tubes, again with a back-up section, can be used. These sampling tubes are designed for analysis by solvent desorption. Breakthrough cannot be ascertained in tubes which are thermally desorbed, as these samples are 'one shot' analysis—that is, repeat testing of the sample is not possible as all the contaminants are destroyed in the analysis.

Figure 7.11 shows the arrangement of a portable low-flow sampling pump and an organic vapour sampling tube and holder. The sampling tube is placed near the breathing zone of the operator, within about 15–30 cm of the nose.

Figure 7.11
Worker being fitted with a sample pump and adsorbent tube

Caution: TAKE CAREFUL NOTE OF SAMPLE PUMP AND MONITORING EQUIPMENT REQUIREMENTS FOR PETROCHEMICAL INDUSTRIES.

The petrochemical industries handle highly flammable materials and therefore any equipment taken on site, even small sample pumps, must be 'intrinsically safe'—that is, the device must not be a source of ignition in these flammable atmospheres. Requirements for intrinsic safety vary from company to company, and approval to use such equipment on site must be obtained before undertaking a monitoring survey (usually through a daily safe work permit system). As a guideline, in the United States monitoring equipment rated Intrinsically Safe by Underwriters Laboratories Inc.® 'UL' is accepted; in Europe, equipment meeting the code ATEX II 2 G EEx ib IIC T4 is accepted as intrinsically safe for use in potentially explosive atmospheres. These ratings are usually displayed on the equipment. Refer to Figure 7.12a, b and c.

7.16.2 PASSIVE ADSORPTION SAMPLING

Sampling for workplace organic vapour contaminants with passive dosimetry badges or tubes is both simple and convenient. Figure 7.13 illustrates a typical organic vapour

Figure 7.12a
SKC® 224 Airchek®

Figure 7.12b
SKC® Pocket pump®

Figure 7.12c
SKC® Airlite®

sampling badge which would be placed in the breathing zone of a worker. Figure 7.14 shows a specific badge for formaldehyde. In these passive approaches sampling pumps are not required; contaminating vapours from the workplace air simply diffuse through a membrane or down a tube into the trapping material of the sampler. Techniques for using this method are to be found in AS 2986.2 *Workplace Air Quality—Sampling and Analysis of Volatile Organic Compounds by Solvent Desorption/Gas chromatography—Diffusive Sampling Method* (Standards Australia 2003b), and US NIOSH methods or UK HSE methods.

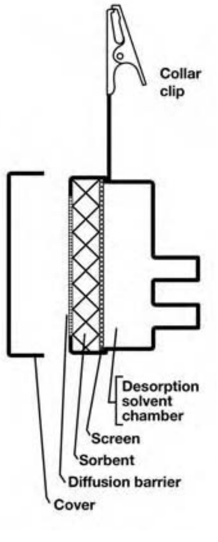

Figure 7.13 SKC® badge

Figure 7.14 UMEX® badge

For large surveys of organic vapours (e.g. printing works, boat building, spray painting, motor body repairs), passive sampling is a very cost-efficient way for the H&S practitioner to undertake vapour sampling. However, before you commence any sampling for organic vapours, contact both the sampling device manufacturer/representative and the processing laboratory. You will have to determine the correct sampler for your task, and allow the laboratory to arrange proper calibration procedures.

This is expensive laboratory time for which you will have to pay. There are a number of passive adsorption badges available for specific contaminants—check with the supplier. But remember, the badges or tubes must be analysed by a competent laboratory.

Once collected and properly capped, the samples are sent to an appropriate laboratory for analysis. As with tube sampling above, the contaminants are desorbed with a strong solvent or by heat. Figure 7.15 shows a laboratory gas chromatograph fitted with an automated thermal desorber suitable for unattended analysis of organic vapour samples.

Figure 7.15 Perkin Elmer® automated gas chromatograph

Limitations with passive sampling

Most passive samplers are designed to work in moving air, a condition which should be met when they are worn by the worker. They are generally not designed to be hung around the workplace to obtain 'workplace environmental' vapour concentrations, unless specifically designated as suitable. Typically the passive sampler must be worn for more than 4 hours to obtain sufficient material for the laboratory to analyse.

If the workplace is being monitored for solvent mixtures (e.g. hexane, methylene chloride and xylene), the H&S practitioner will have to provide very complete information to the processing laboratory, or if possible provide a sample of the solvents.

DO NOT, ON ANY ACCOUNT, TRANSPORT OR SEND EXPOSED SAMPLE TUBES OR BADGES AND CONTAINERS OF SOLVENT IN A SINGLE ENCLOSURE.

Passive badge or tube samplers are extremely sensitive and can pick up significant quantities which may leak or diffuse through seals and inappropriate packaging. This will ruin sampling efforts completely.

7.16.3 IMPINGEMENT INTO LIQUID SAMPLES

A number of gases or vapours contaminating workplaces cannot be successfully trapped on tubes or badges, but they can be trapped by bubbling them through water or some other solvent. These bubblers are called liquid impingers. Contaminated air is drawn by a small pump, at around 1 L/min, through the absorbing liquid (see Figure 7.16a and b). For safety reasons, it is often better to collect area samples rather than personal samples if the absorbing solution contains corrosive substances (acids or alkalis) or hazardous solvents, unless spill-proof impingers can be devised.

Figure 7.16a Liquid impingers

Figure 7.16b Sample pump and liquid impinger (on side) for trapping gases in a laboratory

Impinger trapping has the added advantage that special chemicals are often added to the solution to trap reactive gases. Special personal sampling impingers are also available. These are fitted with a hydrophobic filter for aqueous sampling media only. While impinger methods were quite often used in the past, newer and easier methods have been developed and their use has declined.

Several common gaseous contaminants still collected by impinger are:

- **formaldehyde**, trapped in distilled water or sodium bisulphite (although it is now easier to use passive monitor badges, as shown in Figure 7.14)

- **glutaraldehyde**, trapped in water and reacted with phenylhydrazine
- **isocyanates**, trapped in toluene with methylphenoxypiperazine
- **ozone**, trapped in bisulphite or diacetyldilutidine/water
- certain **pesticides** can be trapped in hexane.

Samples trapped in this way all require laboratory processing to measure the concentration of the contaminants. Laboratory methods include high-performance liquid chromatography, gas chromatography, colorimetric or electrochemical analyses. Again, a competent laboratory should be fully consulted prior to undertaking any sampling should monitoring involving the use of liquid impingers be required.

7.16.4 IMPREGNATED FILTERS

Some vapours can be successfully trapped on filters impregnated with a substance reactive towards the contaminant in question. The method is similar to the vapour tube technique, but has added versatility in that it can simultaneously trap particulates. For instance, an aluminium smelter will produce both gaseous fluoride and particulate fluoride, both of which can be trapped on a filter doped with citric acid. This method can likewise trap aerosol and gaseous forms of certain paints which exist simultaneously in spray operations.

All these sample collection techniques provide time weighted average exposure because they are collected and integrated over a long sampling period. Where information is also needed on short-term or any peak exposure, the H&S practitioner will have to use one of the grab sample techniques in addition to one of these.

7.16.5 COLLECTION OF SAMPLES IN BAGS OR PUMPED CYLINDERS

In some cases the above absorption methods are unsuitable to identify the contaminants in the workplace and other techniques need to be used.

Some samples can be successfully collected in impervious bags (Figure 7.17a and b) or in evacuated pressurised cylinders or canisters (Figure 7.18a and b) and returned to a laboratory for analysis. This technique is required for many of the permanent gases (e.g. oxygen, carbon monoxide, methane, hydrogen) which cannot be trapped by any other means. However, the vessel must retain the sample adequately, without loss. Some plastics will adsorb organic vapours, and small molecules (particularly hydrogen) will diffuse through plastics. The H&S practitioner must ensure that the plastics are specified as suitable for their intended purpose.

In order to obtain a representative sample, bags are simply inflated and emptied and refilled several times with the gas to be tested. Small sampling pumps with a direct outlet can be used for this purpose. A hand-operated pressure pump can also be used to collect gas analysis samples in bags. Pressurised cylinders are under negative pressure and upon opening the valve the air sample is collected. Flow restrictors maintain flow stability over the desired sample period from less than 1 minute to 12 hours. The large cylinder can be fitted with a vacuum gauge to monitor the flow. This is essentially a grab sample, and will only provide information on the contaminants

Figure 7.17a
Positive pressure sample bag

Figure 7.17b
Negative pressure sample bag

Figure 7.18a
Small pressurised canister

Figure 7.18b
Large pressurised canister

present at the time it was collected; it cannot be used to determine the time weighted average. It can only be used as a time weighted sample if the sample has been collected uniformly over the whole shift, that is, the bag or cylinder was filled at the same flowrate over the shift. It is also only indicative of the general environment where the sample was taken, and cannot be equated to personal exposure of the worker. It is, however, useful to evaluate if engineering controls are operating correctly.

7.17 TESTING COMPRESSED BREATHING AIR

Compressed breathing air finds a number of workplace applications. These include underwater breathing apparatus, compressor-fed air-line breathing apparatus for abrasive blasting, spray painting in booths, and breathing sets for fire fighting and rescue work.

In all these situations, the air produced by a compressor must be perfectly fit for breathing under all operating conditions. Compressors can introduce contaminants to the air through incorrect siting of air intakes or through actual operation of the compressor. Oil vapour arises from compressor oil, carbon dioxide from contaminated intake air, and carbon monoxide can arise from partial breakdown of the compressor oil as well as from intake air sources. Water vapour concentration will be higher in the compressed air unless adequately removed by driers.

Special tests need to be conducted on compressed breathing air to ensure its quality. The instrument most widely used for this purpose is the Dräger® Aerotest®. Cylinder air or air directly from a compressor receiver (after passing through a conditioner) can be tested. Air compressor systems require regular testing, and should be thoroughly checked after initial installation or any servicing. This is generally best left to outside expertise.

7.18 TIPS FOR PERSONAL MONITORING

Every personal monitoring sample has a 'story' attached to it and this should be recorded.

- Why was there potential for exposure?
- What chemicals and processes were used?
- What did the worker do during the sampling period?
- Did he or she come in contact with these chemicals?
- What was the physical form of the contaminant?
- How was the chemical used? As a liquid, an aerosol, sprayed?
- Were there any other chemicals used nearby to which this person could have been inadvertently exposed? (Fugitive emissions)
- Was respiratory protection used? Was it worn? Was it suitable? Did it work correctly?
- Was other personal protection used? Gloves, apron? (Often we measure air contaminants, but greater exposure may occur through unprotected skin contact with liquids and vapours.)
- Were engineering controls used? Ventilation/extraction systems?
- Were there any spills, process upsets, known fugitive emissions?

7.19 MONITORING THE WORKER: BIOLOGICAL MONITORING

Monitoring the worker's health directly, instead of the surrounding workplace environment, is another way of checking on the quality of the work environment. This is referred to as **biological monitoring**, and the worker is literally the 'sampling device', accounting for all exposure routes. Biological tests can provide information on the uptake of the substance by the worker, whereas air testing cannot. For example, blood cyanide tests on workers in the cyanide manufacturing industry can indicate whether workers need to be removed from further cyanide exposure.

However, few industries make regular use of biological monitoring, partly because it may involve medical tests and partly because it cannot be done without the complete cooperation of the worker. Confidentiality of medical test results may present another problem. Most H&S practitioners will not become involved in such kinds of sampling. Further detail is found in Chapter 8, Biological and Biological-effect Monitoring.

7.20 COMMONLY OCCURRING GAS OR VAPOUR HAZARDS

This section deals with just a few gases and vapours among the many that occur in workplaces—formaldehyde, ozone, isocyanates, carbon monoxide, chlorinated hydrocarbons and styrene. These substances relate to typical and recurrent complaints which require occupational hygiene investigation. In making use of the H&S practitioner's basic recognition skills, basic toxicological information, assessment methods and control procedures, this section examines:

- typical occurrence
- brief toxicology of the materials
- exposure standards and how the risks are assessed
- possible control procedures which can be recommended.

The six following profiles are very brief and are presented as guidelines. They provide basic information only. The H&S practitioner who encounters any hazardous gases and vapours in the workplace needs to research each one to be fully informed on safety, health and medical factors, and control processes.

7.20.1 FORMALDEHYDE

7.20.1.1 Use and occurrence

Formaldehyde, a chemical widely used in industry, finds applications in urea-formaldehyde glues for particle board, in plastics production, in the rubber industry, in explosives production, in fumigants, sterilants and preservatives, and in the photographic industry. In some lesser applications it finds workplace significance in fabric finishing, acid-curing paints, sandpaper adhesives, urea-formaldehyde insulating foams and in phenol-formaldehyde or urea-formaldehyde resins in foundry moulding. It forms part of the contaminants in cigarette smoke, diesel exhausts and off-gassing from carpets, furniture and furnishing fabrics.

7.20.1.2 Toxicology

Formaldehyde is a flammable and potentially explosive gas. In its polymeric form, paraformaldehyde may undergo explosive ignition due to electrostatic charges built up on sprayed aerosol particles.

The inhaled vapour of formaldehyde is an irritant to both the mucous membranes of the eyes and the respiratory systems and also to the skin. Some individuals show an allergic sensitisation following relatively small exposures. Low concentrations may trigger asthmatic attacks in sensitised persons. Table 7.3 shows the typical response experienced at various levels of exposure.

Table 7.3 Formaldehyde effects

Concentration (ppm)	Observed effect
0.3	Odour threshold
1.0	Odour quite noticeable, slight discomfort
1.5–2	Slight discomfort to eyes, throat and nose
10	Almost unbearable
20	Severe respiratory distress, burning eyes, nose and throat, headache, immediately dangerous to life or health concentration value

Source: NIOSH (1995)

In 2004, the International Agency for Research on Cancer (IARC) classified formaldehyde as a Group 1 carcinogen, that is, carcinogenic to humans.

7.20.1.3 Standards and monitoring

NOHSC has recommended an Australian exposure standard of 1 ppm TWA and 2 ppm STEL for formaldehyde, and classified formaldehyde as a category 2 (probable human) carcinogen (NOHSC 1995). This level of exposure should prevent any acute symptoms, but may not prevent symptoms in sensitive workers. In 2005, ACGIH® recommended a 0.3 ppm ceiling and classified it as a sensitiser and A2 carcinogen (ACGIH® 2005).

As previously discussed, odour is not a good indicator of concentration. Where measurement is required, monitoring at levels above and below the exposure standard can be conducted with indicator stain tubes; cross-sensitivity to other aldehydes, diesel fuel, styrene and some other chemicals should be noted.

For more precise measurement, samples collected by liquid impinger (water or sodium bisulphite) are assessed in the laboratory by the chromatropic acid method. A direct reading diffusion sampler is now available for TWA personal sampling (see Figure 7.14).

7.20.1.4 Controls

Process control in manufacturing provides the best means of preventing exposure. Where specific sources of formaldehyde occur in a workplace, ventilation is the appropriate control procedure. For example, in fabric pressing, mortuaries, pathology laboratories, foundry moulding and many particleboard manufacturing plants, exhaust ventilation can maintain exposure levels well below the exposure standard.

For diffuse sources, such as off-gassing particle board, urea-formaldehyde insulation or carpet, local exhaust ventilation (LEV) is ineffectual and natural or forced dilution ventilation is the only solution. Some materials off-gas formaldehyde for periods up to 12 months after manufacture, and off-gassing problems may worsen during hot and humid weather. Significant problems occur when off-gassing materials are found in an air-conditioned space. In such cases, the fresh air make-up must be increased until the problem diminishes to tolerable proportions.

Full face respiratory protection utilising acid gas filters (cartridges or canisters) should be provided for emergency escape systems, or when control or ventilation systems cannot maintain an acceptable work environment in those places where gaseous formaldehyde is used.

7.20.2 OZONE

7.20.2.1 Use and occurrence

Ozone (O_3), a toxic gas of distinctive odour, is normally a constituent of Earth's upper atmosphere. It can be produced by the action of ultraviolet light on oxygen and by high voltage electric discharge sources which ionise air, such as lightning. Ozone is an extremely reactive compound, breaking down to normal diatomic oxygen and a free oxygen radical. This reactivity enables ozone to oxidise organic materials, permitting it to serve as a strong airborne bactericide, but also makes storage difficult.

Ozone occurs both intentionally and sometimes incidentally in workplaces. Ozone finds considerable use as a bactericide in garbage rooms in hospitals, kitchens, fish processing plants, cold stores and restaurants, and in water disinfection plants. Because the ozone is generated from air on demand, swimming pools can be effectively treated without the risks associated with traditional bulk chlorine storage. Ozone can be used to pretreat plastic surfaces prior to printing and it can be used as a bleach.

Ozone occurs as an unintentional contaminant around office photocopier machines due to the action of high intensity lamps on oxygen. Ozone build-up is not uncommon in areas around copying machines without extraction, in poorly ventilated offices. High pressure xenon lamps in projection lamps for theatre use, and UV sources in laboratory scientific equipment, can also produce ozone which may require exhausting from the workplace. Ultraviolet ink, photo-resist and photo-etch curing processes all require exhaust extraction; this may be provided by the cooling air to the lamp. Electrical discharges which accompany electrostatic precipitators, static eliminators and electric arc welding all produce ozone which can contaminate workplace atmospheres. The intense radiation from the arc in some welding will produce ozone, even though the immediate area is shielded with an inert gas.

7.20.2.2 Toxicology

Ozone is a powerful irritant to the mucous membrane of the eyes and the respiratory tract, and higher concentrations can cause pulmonary oedema. Table *7.4* illustrates the effects of ozone at various concentrations.

Table 7.4 Ozone effects

Observed effect	Concentration (ppm)
Odour threshold for normal persons	0.003–0.01
Typical level in major cities	0.02–0.04
NOHSC exposure standard	0.1
Respiratory irritation, headache, nausea, bacteria susceptibility and pulmonary oedema with extended exposure	0.5
Lung changes, chest pain	1–2
Immediately dangerous to life and health	5

Source: NIOSH (1995)

7.20.2.3 Standards and monitoring

The NOHSC exposure standard for ozone is 0.1 ppm (as a peak) (NOHSC 1995), whereas ACGIH® has a range of TLVs® from 0.05 to 0.2 ppm TWA, depending on the work activity (ACGIH® 2005). At these concentrations, ozone is very noticeable by smell.

A simple test for suspected ozone leaks is provided by a moist starch/potassium iodide paper which turns blue on exposure to ozone. Stain indicator tubes are useful in the range 0.05–2 ppm, but other oxidant gases will interfere with the determination. Laboratory-based measurements on liquid impinger samples or continuous ozone monitors can provide more sensitive and specific estimates.

7.20.2.4 Controls

Ozone produced in machines should be either destroyed by a catalytic filter such as activated carbon, or vented to the atmosphere in a way that no hazard is present. Good ventilation around photocopiers is also recommended, usually in open office spaces; exhaust extraction may be required if the photocopier is located in an enclosed area with poor ventilation.

Where ozone occurs in work situations such as welding, control by ventilation is always the most effective.

Respiratory protective equipment with specially treated carbon filters is suitable for concentrations up to 40 ppm; check with the equipment supplier for suitability. Major concentrations from process gas leaks require mandatory use of self-contained or air-line breathing apparatus.

7.20.3 ISOCYANATES

7.20.3.1 Use and occurrence

Isocyanates are important in a number of chemical processes, notably as one of the building blocks in production of polyurethanes. Polyurethanes can take the form of rigid and flexible foams, elastomeric rubbers, paints, inks, varnishes, adhesives and other products. Various commercial processes using isocyanates in polyurethane foams are shown in Figure 7.19a, b and c.

Figure 7.19b Conveyor with paper lining, ventilated tunnel

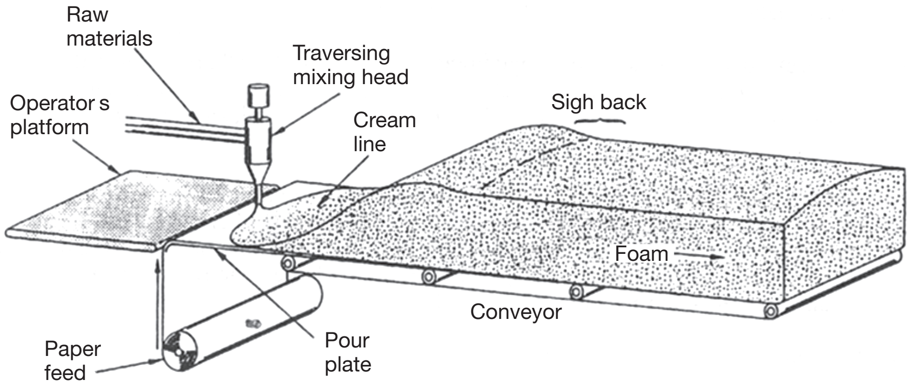

Figure 7.19c Polyurethane foam manufacture

Several different isocyanates are used industrially. The common types are liquids at room temperature, and are highly reactive. One aromatic isocyanate, toluene diisocyanate (TDI), is used for making the common sponge foam, for flexible high density elastomers and for some timber and cork clear flooring finishes; another, methylene bisphenyl isocyanate (MDI), finds use in electrical insulating resins, no-bake foundry moulds and hard packaging foams. Aliphatic isocyanates (e.g. 1,6 hexamethylene diisocyanate) have less long-term light discolouration and so find use in paints and surface finishing applications. Two-pack paints may be a source of isocyanates in many workplaces.

7.20.3.2 Toxicology

The toxicity of isocyanates gives them an unenviable health record. On the skin, isocyanates may cause dermatitis. They can cause chemical conjunctivitis if splashed in the eyes. In high airborne concentrations, the vapours have a primary irritant effect on the respiratory system, causing coughing and dry throat. These high exposures can cause immediate or delayed asthma, and decreased respiratory function with the possibility of interstitial fibrosis or pulmonary oedema, which can prove fatal in rare cases. Symptoms may persist after cessation of exposure. Sensitisation of some workers occurs, with asthma symptoms recurring whenever there is exposure to vapours or aerosols of the material; hypersensitivity to minute exposures occurs in a few workers. Up to half of all occupationally-related asthmas may be caused by isocyanate exposure; in some workplaces 10 per cent of workers have been found to be affected.

Isocyanate reactivity in the human biological system is most probably related to the isocyanate chemical radical (-N=C=O). Some biological tests for isocyanate exposure are possible, but are restricted to special immunological testing laboratories. Those compounds with more free -NCO groups show greater reactivity, and many industrial formulations now contain pre-polymerised material to reduce the availability of the unreacted -NCO radicals.

TDI has a relatively high vapour pressure at room temperature (0.02 mm Hg) and strict controls are required to prevent TDI contamination of workplace air. MDI has a much lower vapour pressure (0.00014 mm Hg) and is relatively easy to handle. At room temperature, MDI will not produce vapour concentrations at the TWA exposure standard. At temperatures above 40°C, MDI vapour will begin to be released, thus any high-temperature curing of resins should be very carefully controlled. While vapours are most significant when considering the volatile TDI, aerosols are an important form of airborne contamination when dealing with sprayed isocyanate paints.

7.20.3.3 Standards and monitoring

The NOHSC exposure standard for all isocyanate forms, expressed in terms of the free isocyanate groups (-NCO), is 0.02 mg/m^3 TWA with a STEL of 0.07 mg/m^3 (NOHSC 1995). NOHSC has also designated isocyanates a sensitiser notation. (ACGIH® lists the isocyanate forms under their specific chemical names, e.g. MDI 0.005 ppm TLV®-TWA, while TDI is listed as 0.005 ppm TLV®-TWA with a STEL of 0.02 ppm with a notation of sensitiser (ACGIH® 2005).)

The H&S practitioner testing for isocyanates is generally limited to testing for the aromatic isocyanate vapours (TDI and MDI) with direct reading badges. Complete monitoring for vapours and aerosols can only be carried out effectively by laboratory-based procedures. Laboratory tests will measure for the presence of any reactive -NCO radicals, whether in monomers or polymers. Sampling should be taken to reflect personal exposures; that is, personal monitoring is better than area monitoring. The HSE MDHS No. 25/3 (HSE 1999b) or equivalent requires a high performance liquid chromatograph fitted with two detectors. These techniques are beyond all but specialist laboratories.

Because of the extreme hazard which can occur with isocyanates, odour provides *no* protection (e.g. the NOHSC exposure standard may be one-tenth to one-twentieth of the odour threshold).

7.20.3.4 Controls

The safe use of isocyanates depends on preventing inhalation of their vapours, aerosols or dusts. Significant attention must be given to all aspects of design and operation of plant to prevent escape of vapours or aerosols into the breathing zones of unprotected workers.

All storage areas for isocyanates need to be well ventilated to prevent excess build-up of vapours. Sometimes cold or cooled storage can be used. Spilt materials need to be cleaned up using correct decontamination procedures by workers trained for the purpose, equipped with the correct personal protective equipment including respiratory protection. Reference should be made to the supplier's material safety data sheet (MSDS).

Process controls consist of enclosures and/or ventilation. Processes should be electrically interlocked with extraction systems. Where hot processes are involved, the rate of release of isocyanate vapour is dramatically increased, and adequate provision should be made for enclosure and extraction. Ventilation should be sufficient to prevent any exposure above the exposure standard, with vapours always drawn away from the operator's breathing zone by adequate ventilation rates, and the use of baffles, shields, etcetera.

Where engineering control methods are not feasible or capable of keeping the isocyanate concentrations below the exposure standard, respiratory protection is necessary. The level of protection depends on the material:

- **TDI** Use compressed air-line or self-contained breathing apparatus for all areas where the exposure standard can be exceeded, and for all emergency procedures where spills exceed about 10 ml. Full-face type negative pressure filter (canister) respirators are suitable for cleaning up of small spills and for emergency evacuation.
- **MDI** Use compressed air-line type only for any spraying of paints, foams or adhesives, or when working with high-temperature heated resins where the exposure standard can be exceeded. Use full-face type negative pressure filter (canister) respirators for any other work situations. In spraying of 2-pack polyurethane paints, concentrations of the reactive -NCO radical in the aerosol can reach 30–50 times the designated STEL.

7.20.3.5 Training and education

Because of the potential hazards associated with industrial use of isocyanates, proper employee training and education must be undertaken by the employer in every workplace. This must include knowledge of the hazards, handling and storage, all plant procedures for use, safety procedures, clean-up procedures, use of respiratory protective devices and their proper maintenance, and early reporting of any respiratory symptoms.

7.20.3.6 Medical requirements

Pre-placement medical examination is advisable for all new isocyanate workers so that potentially susceptible individuals can be appropriately advised. Ideally, those workers who already have a predisposition to asthma should not be employed in areas where isocyanates are used. Isocyanates are scheduled hazardous substances and therefore health surveillance may be required, depending on the significance of risk. This will include respiratory function testing. If any employees are found to be suffering respiratory symptoms, the work environment should be investigated, and workers showing respiratory distress should not be allowed to return to work with isocyanates.

For explanation in greater detail, any H&S practitioner whose workplace employs isocyanates in one of its various forms should consult an appropriate code of practice or guidance note dealing with the safe use of isocyanates, such as 'Controlling Isocyanate Hazards at Work' by Worksafe Western Australia (2000).

7.20.4 CARBON MONOXIDE

7.20.4.1 Use and occurrence

Carbon monoxide is a colourless and odourless toxic gas, which burns with a pale blue flame. Prior to the widespread introduction of natural gas supplies, town gas supplies contained carbon monoxide. Town gas is still used as an oven gas in coke and steel works. Carbon monoxide finds use as an inerting agent for some processing reactions, but workplace concerns arise principally from incomplete combustion of fuels in ovens and furnaces, internal combustion engines (e.g. forklifts used in cold stores), and in coal mines. Smouldering materials (e.g. poured metal moulds in foundries and building fires) produce considerable quantities of carbon monoxide. Although workers and vehicle drivers are generally familiar with the dangers, accidents due to carbon monoxide poisoning are relatively common. Escape from a dangerous situation is often impossible, because the first indication of gross exposure may be collapse.

7.20.4.2 Toxicology

Carbon monoxide falls in the class of chemical asphyxiants which block the transport of oxygen in the blood. Carbon monoxide in the air displaces inhaled oxygen and is carried to the tissues of the body, thereby depriving them of oxygen, so that a form of asphyxia results. Carbon monoxide has a greater affinity for haemoglobin than does oxygen (300 times) and the bond is about 20 times as strong. When carrying carbon monoxide, the blood does not become the bluish colour of venous blood as in cases of normal asphyxia; the blood and the lips remain a bright cherry red. Central nervous system tissues and the brain are the most susceptible. Methylene chloride, a commonly used industrial solvent, metabolises to carbon monoxide and may produce chemical asphyxia after exposure to high concentrations of the solvent.

Table 7.5 lists the Australian exposure standards for carbon monoxide.

Table 7.5 Australian exposure standards for carbon monoxide

Time	TWA (ppm)	STEL (ppm)
8 hr	30	no value
1 hr	no value	60
30 min	no value	100
15 min	no value	200
<15 min	no value	400

Source: NOHSC (1996, p. 23)

Even very low concentrations of carbon monoxide in air are dangerous. Discomforting effects are noticeable at 50 ppm, and even a short exposure to 2000 ppm will result in asphyxia and death. Symptoms of carbon monoxide poisoning include, progressively, headache, nausea, drowsiness, fatigue, collapse, unconsciousness and death. These states correspond to increasing percentages of blood carboxyhaemoglobin (COHb), from 10 per cent to 40 per cent. Smokers may have a blood level from 5 per cent to 10 per cent carboxyhaemoglobin.

7.20.4.3 Standards and monitoring

The Australian exposure standard for carbon monoxide is 30 ppm. This exposure standard has been considered necessary to reduce the likelihood of blood COHb rising above 5 per cent, at which level those with detected or even undetected cardiovascular disease can be at risk. The standard will also contribute to providing protection from adverse behavioural manifestations from CO exposure at low levels as well as preventing acute CO poisoning. There are some variations possible for higher short-term exposures for reduced periods, as shown in Table 7.5. Exposure standards vary around the world; for example, in the United States, ACGIH® listed the carbon monoxide TLV®-TWA at 25 ppm (ACGIH® 2005).

Because of the insidious nature of this substance, monitoring for carbon monoxide should be carried out in work areas *wherever* there is a possibility of the gas being present. Spot monitoring can be effectively carried out using stain tube monitoring equipment. Concentration measuring ranges are available from as low as 2 ppm up to 1500 ppm for workplace monitoring, and up to several per cent for special applications. Specific direct reading monitors are readily available for carbon monoxide from a variety of manufacturers (MSA, Dräger®, RAE Systems); many are available as pocket personal dosimeters, fitted with visible and audible alarms which can be set at predetermined levels.

TWA monitoring in the workplace can be undertaken using direct reading diffusion monitors (e.g. Dräger® diffusion tubes). These tubes are calibrated from 50 to 600 ppm hours; the absolute reading is divided by the number of hours of exposure. More elaborate monitoring techniques (infrared spectroscopy, gas chromatography) are available for special situations such as coal mining.

7.20.4.4 Controls

Engineering controls are mandatory to prevent build-up of the gas and subsequent exposure of workers. Underground car parks and tunnels must be fitted with extraction systems to remove vehicle exhausts. Ovens, gas furnaces and burners must be correctly vented to carry away both burnt and incompletely burnt combustion products.

Respiratory protective equipment is not recommended for long-term protection against carbon monoxide since it is more appropriate to use proper ventilation. Emergency escape equipment consists of either self-contained breathing apparatus or a self-rescuing gas converter which turns carbon monoxide into carbon dioxide, along with the accompanying production of much heat. Firefighting and rescue equipment is usually self-contained breathing apparatus.

7.20.4.5 Training and education

All workers exposed to carbon monoxide (e.g. from coke oven gases) must be instructed and trained in safe work procedures and in the appropriate use of self-contained breathing apparatus.

7.20.4.6 Medical requirements

Heavy smokers are at greater risk of carbon monoxide ill effects because they already have a proportion of their haemoglobin incapacitated. Workers with emphysema may also be at greater risk. Because of the possibility of severe health problems in those workers who have cardiovascular disease, exposure to carbon monoxide should be restricted to ensure that the carboxyhaemoglobin content of all workers' blood is maintained below 5 per cent.

7.20.5 CHLORINATED HYDROCARBONS

7.20.5.1 Use and occurrence

Chlorinated hydrocarbons, produced by substituting a few chlorine atoms for hydrogen atoms in petroleum hydrocarbons, find extensive use as chemical solvents and chemical building blocks for plastics. Besides being strong non-polar solvents, they tend to be generally of low flammability and to evaporate easily. These properties make them attractive as fast-drying 'safety' solvents for degreasing, electrical and dry cleaning purposes. They are used worldwide in millions of tonnes each year; some are further halogenated with fluorine to form the environmentally sensitive chlorofluorocarbons. Table 7.6 shows some typical solvent uses of chlorinated hydrocarbons.

Table 7.6 Chlorinated hydrocarbons: solvent uses

Solvent	Use
Trichloroethylene and 1,1,1 Trichloroethane	Metal degreasing, safety solvents
Carbon tetrachloride	Little use now, but formerly used as a drycleaning agent and fire-extinguishing agent in the 1950s–60s
Methylene chloride	General solvent, foam blowing, aerosols, paint stripping solvent, perspex solvent, adhesive solvent, refrigerant, aerosol propellant
Tetrachloroethylene (perchloroethylene)	Drycleaning

7.20.5.2 Toxicology

Occupationally-related illnesses, deaths and near-fatalities with chlorinated hydrocarbons still occur. Chlorinated solvents widely exhibit the property of causing skin irritation by removing skin oils, causing chemical irritation, dermatitis and possible entry of bacteria through fissures created in damaged tissue. Chloracne, a severe skin eruption, can be caused by a few chlorinated solvents (as well as by more complex chlorinated compounds). However, inhalation is the major route of entry of chlorinated solvent vapours. The primary effect of inhaled chlorinated hydrocarbon vapours is central nervous system depression, resulting in dizziness, drowsiness, nausea and vomiting. These symptoms have led to serious accidents; they have also given rise to the phenomenon of solvent sniffing. The use of chloroform as an anaesthetic in past years is well known. Extreme overexposure to chlorinated solvent vapours may cause respiratory paralysis and circulatory failure. Cardiac sensitisation with possible arrhythmia may occur in a few individuals. Chlorinated solvent hydrocarbons also present a problem in workplaces where welding is carried out; many chlorinated hydrocarbons can produce the extremely toxic gas phosgene by oxidative breakdown in the welding arc. Smoking where vapours are present can result in inhalation of irritant and toxic breakdown products. Inhalation of several chlorinated hydrocarbon solvent vapours can lead to addiction, and this has occurred in some workplaces.

Longer term effects have been caused to the body's target organ, the liver. Carbon tetrachloride has the most severe effect, followed by tetrachloroethylene, trichloroethylene, methylene chloride and 1,1,1 trichloroethylene (methyl chloroform). Carbon tetrachloride also causes liver damage and tumours. Chloroform can cause cancers and methylene chloride is listed by NOHSC (1995) and ACGIH® (2005) as a suspected carcinogen. Methylene chloride is metabolised to carbon monoxide and so also presents additional short-term toxicity of carbon monoxide exposure. A more worrying property is that many chlorinated hydrocarbon vapours, in combination with alcohol or acetone exposure, result in enhancement of the toxic effect exhibited by the chlorinated hydrocarbon.

7.20.5.3 Standards and monitoring

Table *7.7* shows current exposure standards and STELs for common chlorinated hydrocarbons.

Table 7.7 Australian exposure standards for chlorinated hydrocarbons

Compound (synonym)	Exposure standard TWA (ppm)	STEL (ppm)	Other comments
Carbon tetrachloride	0.1	no value	Carc 2, skin
Chloroform	2	no value	Carc 3, skin
Methylene chloride (Dichloromethane)	50	no value	Carc 3, skin
1,1,1 Trichloroethane (Methyl chloroform)	100	200	—
1,1,2,2 Tetrachloroethane	1	no value	Skin
Trichloroethylene (Tri)	10	40	Skin
Tetrachloroethylene (Perchlor)	50	150	Carc 3
Trichlorofluoromethane (Freon 11)	1000	peak limitation	—
Vinyl chloride (monomer)	5	no value	Carc 1

Source: NOHSC (1995)

There are several systems for monitoring chlorinated hydrocarbons:

- The simplest test for chlorinated solvent vapours employs a flame lamp fitted with a copper cone. The green-blue colour of the flame can be empirically correlated with vapour concentration in the air. However, this method lacks the sensitivity needed for many solvents and can be a safety hazard where other flammable solvents are used in mixtures. A number of modern, non-specific analysers working on photo-ionisation (PID) or electron capture principles have replaced the flame lamp. For example, the ToxiRAE® PGM30® PID can be set to monitor 1,1,1 trichlorethylene.

- Grab sample monitoring for chlorinated solvents can be conducted with indicator stain tubes, but cross-sensitivity is almost universal. Therefore, indicator tubes are best limited to single contaminant situations.
- Direct in-field monitoring of the workplace with a PID, a portable infrared analyser such as a MIRAN® or a portable gas chromatograph provides information on any peaks in exposure and can usually distinguish between different chlorinated solvent vapours.

TWA monitoring can be conducted for most chlorinated hydrocarbon solvents using activated carbon badges or pumped tube samplers. An occupational hygiene laboratory can advise on the type of sampling tubes required.

7.20.5.4 Controls

Choose the compound of lower toxicity whenever these solvents are absolutely necessary. Wherever possible, chlorinated hydrocarbon degreasing should be substituted by hot detergent methods. Where it is not technically feasible to substitute less hazardous materials, process control is required. Plant enclosure, of the kind used in closed-circuit drycleaning machines, should be used to prevent or minimise vapour escape. Refrigeration or condensers on vapour degreasers must be maintained at optimum performance, and work procedures for loading and unloading of work pieces from tanks and baths must not permit excess vapours to enter the workplace.

When enclosure of plant is not possible, properly designed LEV methods should be employed to exhaust fugitive vapours and prevent them spreading to the workplace. Good general ventilation is also required, except in the case of open degreasing baths, where drafts need to be avoided because this would increase evaporation and hence the airborne concentration. Drycleaning machines and newly cleaned clothes require adequate ventilation of solvent vapours. Most chlorinated solvent vapours are heavier than air and will tend to accumulate in the bottom of tanks, baths and so on. A cold tank with no liquid in it may still contain lethal concentrations of vapour. Work in such confined spaces requires proper training and correct procedures, stand-by person, testing of space prior to entry, and correct respiratory protective equipment where necessary.

The degree of personal protection required depends on the situation. Where vapour hazards are not severe, respirators with organic vapour filters can be used. However, because of the skin hazard, dermal protection (impervious gloves, aprons) should be worn wherever hand contact or splashes are likely. Eye protection against splashes may also be needed. Any work in or entry into confined spaces containing vapours which exceed the exposure standards requires use of air-supplied or self-contained breathing apparatus.

7.20.5.5 Training and education

All workers handling chlorinated solvents should be notified of their harmful effects, and trained in their correct handling, safe work practices, use of respiratory equipment, and emergency procedures. Any intentional inhalation of these narcotic substances should be reported.

7.20.5.6 Medical requirements

Regular health surveillance for exposure is not required for well-controlled workplaces, although some biological monitoring of urine can be conducted (e.g. for trichloroethylene). Medical practitioners should be aware of the short-term acute effects of each chlorinated solvent found in the workplace. In the longer term, observe for skin problems, possible addiction, cardiac sensitisation and the range of solvent neurotoxic effects.

7.20.6 STYRENE

7.20.6.1 Use and occurrence

Styrene, or vinyl benzene, is a monomer used widely in the chemical and processing industries. It is well known for its use in polystyrene and styrene foam, but is also incorporated into other plastics. Downstream industry uses large amounts of polystyrene in the glassfibre-reinforced plastic construction of boats, swimming pools, tanks, vehicle panels, bath wares, furniture and so on. Although styrene monomer exerts a relatively low vapour pressure (boiling point 145°C), it has a very low odour threshold of about 0.2 ppm and consequently good warning properties.

7.20.6.2 Toxicology

Styrene monomer causes skin irritation, and affects the eyes and upper respiratory tract. It also affects the central nervous system, causing effects ranging from tiredness, drowsiness and memory impairment from mild exposure, to impaired motor coordination and narcosis from high-level exposures. Some changes may be long lasting. Commercial formulations of the styrene monomer may be stabilised with butylcatechol or hydroquinone, which are both sensitisers.

7.20.6.3 Standards and monitoring

The NOHSC exposure standard for styrene (monomer) has been set at 50 ppm TWA with a STEL of 100 ppm (NOHSC 1995). Because many applications use sprayguns to deliver the styrene to the workplace, concentrations of styrene in the breathing zone of operators can be well in excess of this standard, for example, a TWA of 180 ppm and peak exposure inside a tank of 1800 ppm. Figure 7.20a, b and c show typical work practices that can lead to elevated exposures of styrene vapour.

Grab or instantaneous sampling in workplaces can be undertaken with indicator stain tubes, a PID or a portable field gas chromatograph. In continuous mode, short-term excursions can be identified and can help pinpoint the stages of an operation which contribute most to the exposure.

Figure 7.20a Fibreglass boat manufacture

Figure 7.20b Surfboard manufacture

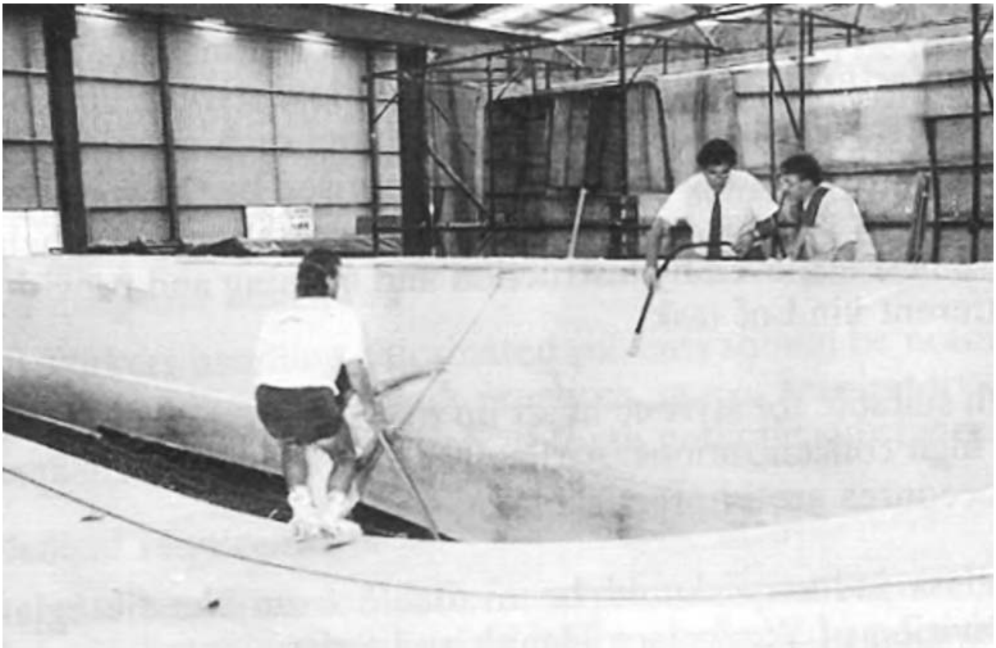

Figure 7.20c Fibreglass boat construction

TWA measurements require monitoring either with diffusion badges or with long-term pumped tube samples. These samples are submitted to a consulting laboratory for measurement by gas chromatography.

7.20.6.4 Controls

Control of the styrene by engineering controls—ventilation—is the most appropriate, but may not always be the most practical, particularly for small manufacturing industries. Specialised low styrene emission (LSE) resins may help in the glass-reinforced plastic industry, and work procedures such as using long-handled rollers may help limit exposures. Minimising the amount of styrene vaporised by a spray gun, for example, by using a low-pressure air gun rather than an airless spray gun, also helps reduce exposure, contrary to expectation. Appropriate work practices are best achieved by instruction and training, and provision of ventilation practices appropriate to each different kind of task.

Filter (cartridge or canister) respirators are both suitable for styrene in air up to concentrations of about 500 ppm, but the cartridge or canister will have a limited effective lifetime at high concentrations. Air-line respirators are the cheapest means of providing fresh air where control procedures are impracticable.

7.20.7 OTHER GAS OR SOLVENT HAZARDS

Of the many other hazardous gases or organic vapours to be found in the workplace, the most important include simple asphyxiants, irritants such as the acid gases, ammonia and volatile amines and a group of common fumigants and sterilants.

7.20.7.1 Simple asphyxiants

Methane, nitrogen and carbon dioxide are the most common simple asphyxiants of which the H&S practitioner needs to be aware.

Methane is produced naturally by biodigesters (sewage plants and silage), in coal mines, and may be found in some natural gas supply systems. Nitrogen exists naturally in the atmosphere (about 78 per cent by volume) but atmospheres in which oxygen is replaced by additional nitrogen may lead to asphyxiation. Clearly, facilities using compressed or liquid nitrogen under enclosed conditions could present a risk. Liquid nitrogen expands by a factor of 700 when going from liquid to vapour. Nitrogen can also be used in tanks and vessels to 'blanket' flammable liquids and create atmospheres which have minimal explosivity. Carbon dioxide is produced by the burning of carbon-based fuels, from bacterial fermentation and numerous industrial chemical reactions. Compressed carbon dioxide is used extensively.

Any of these asphyxiant gases may present an occupational health risk in enclosed or confined spaces—in mines, wells, tunnels, vats, ships' holds, silos, small rooms and so on. In concentrations which cause significant depletion of oxygen to below 19.5 per cent, all asphyxiants represent a risk to life. All are colourless, without odour or other warning properties, so it is possible for the worker to be overcome before being aware of the danger. At 5 per cent, carbon dioxide may produce shortness of breath and headache. Detection and monitoring of carbon dioxide is relatively easy. Indicating stain tubes are available from the atmospheric background level (0.03 per cent) to 20 per cent. Detection of nitrogen is difficult, and it is often far better to measure for the oxygen deficiency. Although there are few simple indicator tests, the presence of methane or other hydrocarbon gases may be identified by a combustible gas detector. These are typically used for determining whether explosive atmospheres exist in confined spaces. Refer to Section 7.21 on testing for explosivity in nitrogen-rich atmospheres.

For above-ground workplaces, adequate ventilation by fresh air will provide atmospheres safe from asphyxiating gases. Where entry into workplaces with insufficient oxygen is required, only a self-contained breathing air system or supplied air system is to be used.

7.20.7.2 Acid gases

There are some six commonly encountered acid gases in the workplace which H&S practitioners could be expected to deal with. They are hydrogen sulphide (H_2S), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), hydrogen chloride (HCl), hydrogen cyanide (HCN) and hydrogen fluoride (HF).

Acids are widely used in metal treatment for cleaning, pickling, etching, for acid catalysis, neutralising, dissolution of metals, and for water treatment. Gaseous hydrogen cyanide is used in fumigation. In addition, acid aerosols of sulphuric and other acids can be encountered in electroplating, battery manufacture and large-scale battery use. In the workplace, many of the acid gases also arise as by-products from industrial processes. Roasting of sulphur ores of copper, lead and zinc produces sulphur dioxide. Hydrogen sulphide is produced in anaerobic (oxygen-deficient) breakdown of organic matter which contains sulphur, and gaseous fluorides are produced during the production of superphosphate fertilisers. A range of acid gases may be produced during decomposition of organic mould binders in foundries, and diesel vehicle exhausts produce oxides of nitrogen.

The toxicology of these acid gases varies from substance to substance. All are irritants and tend to be highly corrosive to the mucous membranes of the respiratory system and the eyes, and may produce an acidic taste. The acids destroy body tissue, particularly the skin, from accidental splashes, and may affect teeth. Sulphur dioxide can cause asthmatic responses. Both hydrogen sulphide and hydrogen cyanide also act as chemical asphyxiants. Hydrogen fluoride may cause deep tissue and bone destruction which is difficult to heal.

Because of their extreme irritant nature, all these acid gases are listed in the exposure standards either with peak limitations or with short-term exposure limits, specifically for the purpose of limiting their irritation. Measurements of acid gases in the workplace can be most conveniently made using indicator stain tubes, although cross-sensitivity can be a significant problem. More elaborate laboratory-based methods are available and can be required for mixtures.

Exhaust ventilation should be used to control acid gases and aerosols, particularly above acid pickling and electroplating baths where worker access is required. This also helps in controlling the inevitable corrosion which occurs with the use or presence of acids in the workplace. Personal protective equipment must be used to protect against splashes to skin and eyes, and acid gas respirator filters are available for use against all inhaled acid gases.

7.21 CONFINED SPACES: A SPECIAL HAZARD

Confined spaces present a number of special hazards in the workplace—risk of explosion, engulfment, oxygen deprivation, and being overcome by toxic gases and vapours. The factors taken for granted in a normal workplace, such as adequate ventilation, no longer exist, and thus adequate oxygen levels must become a consideration in a confined space. The potential to increase the level of airborne contaminants increases dramatically. In fact, more occupational health-related deaths occur in confined spaces than anywhere else. A common scenario involves a worker who drops a tool in a pit and climbs in to retrieve it—he collapses; his workmate assumes he has had a heart attack and enters the pit to rescue him—inevitably both workers die due to lack of oxygen, or by being overcome by toxic gases, or both.

NEVER ENTER A CONFINED SPACE UNTIL THE ATMOSPHERE HAS TESTED AS SATISFACTORY.

Confined space means a space in any vat, tank, pit, pipe, duct flue, oven, chimney, silo, reaction vessel, container, receptacle, underground sewer, shaft, well, trench, tunnel or similar enclosed or partially enclosed structure, if that space:

- is to be entered by any person
- has limited entry or exit that makes it physically difficult for the person to enter or exit

- contains harmful levels of any contaminant, or unsafe oxygen levels, or any stored substance, except liquids, that could cause engulfment.

The definition of a 'confined space' varies from state to state—the definition above has been taken from the Victorian regulation and is perhaps the most unambiguous.

Some of the risks associated with the presence of chemical and physical hazards in confined spaces include:

- loss of consciousness, injury or death due to the immediate effect of contaminants
- fire or explosion from the ignition of flammable contaminants
- asphyxiation resulting from oxygen deficiency when the oxygen level is below 19.5 per cent
- enhanced combustibility and spontaneous combustion resulting from an excess of oxygen when the oxygen level is greater than 23.5 per cent
- asphyxiation resulting from engulfment by 'stored' material, e.g. grain, sand, flour, fertiliser.

Undertaking work in confined spaces may also greatly increase the risk of injury from:

- **Mechanical hazards** Associated with plant and equipment which may result in entanglement, crushing, cutting, piercing or severing of parts of a person's body. Examples of sources of mechanical hazards include equipment such as augers, agitators, blenders, mixers, stirrers and conveyors.
- **Ignition hazards** Associated with plant and equipment inside or in the vicinity of the confined space. The presence of ignition sources where a flammable atmosphere also exists may result in fire or explosion and the death or injury of workers. Examples of ignition sources include open flames, sources of heat, static or friction, non-intrinsically safe equipment, welding and oxy-cutting, hot riveting, hot forging, electronic equipment such as cameras, pagers and mobile phones, and activities which generate sparks such as grinding, chipping and sandblasting.
- **Electrical hazards** May result in electrocution, electric shock or burns.
- **Presence of uncontrolled substances** The presence or introduction of substances such as steam, water or other liquids, gases or solids may result in drowning, being overcome by fumes, engulfment or other harm.
- **Noise** Noise levels can be greatly increased in confined spaces.
- **Manual handling** Hazards arise from carrying out work in cramped, confined areas, and these may be increased by the use of personal protective equipment such as an air-line or harness which restricts movement, grip and mobility.
- **Radiation** The health effects depend on the type of radiation involved. Sources of radiation include: lasers, welding flash, radio frequency (RF) and microwaves, radioactive sources, isotopes and X-rays.
- **Environmental hazards** These include heat or cold stress arising from work or process conditions, wet or damp environments, slips, trips and falls arising from slippery surfaces.
- **Biological hazards** There are a number of infectious diseases which have the

potential to be contracted from microbes during work in confined spaces. Contact with fungi may cause skin disease and exposure to airborne fungi may result in respiratory illness. Exposure to mites in infected grain may result in dermatitis. Viruses and bacteria may also present a hazard. Exposure to leptospirosis and *Escherichia coli* are of particular concern for work in sewers. Insects, snakes and vermin are also hazards.
- **Traffic hazards** These hazards are a concern where confined-space entry or exit points are located on walkways or roads and there is the potential for workers entering or exiting the space being struck and injured by vehicle traffic, such as cars or forklift trucks. The potential for others to fall into the space may also exist.

There can be a number of situations in which the oxygen level will change (decrease) and/or other gases will be generated, depending on the work undertaken or conditions in the confined space. Some examples are:

- Removal of oxygen by activated carbon, or by some soils undergoing microbiological activity.
- Decrease in oxygen level by the oxidation (rusting) of freshly grit-blasted metal surfaces.
- Reaction of hydrocarbons, in the presence of catalysts such as alumina, to partially oxidise to produce carbon monoxide and decrease oxygen levels, thus producing two hazards.
- Decrease in oxygen and the generation of toxic gases from the reaction of pyrophoric materials. Pyrophoric iron will self-ignite in the presence of oxygen.
- The hazard of hydrocarbons under a 'nitrogen blanket'. Some vessels are purged with nitrogen gas to minimise the risk of flammability—a nitrogen rich atmosphere. Not only is there insufficient oxygen to support life, but if the explosive limits are measured in this nitrogen blanket with an explosimeter (LEL or lower explosive limit), a false low reading can be obtained, thus underestimating the risk.

In summary, confined space situations require special procedures, training and testing to ensure safe operations which will protect the worker. More information can be found in the Worksafe Victoria *Code of Practice for Confined Spaces* (1997) and Australian Standard® AS/NZS 2865 *Safe Working in a Confined Space* (Standards Australia 2001).

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8. Biological and biological-effect monitoring

Dr John Edwards MAIOH

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8.1 INTRODUCTION

While a typical view of OH&S practice recognises that it includes measurement of the environment to which workers are exposed, a broader view should include the use of other strategies and tools to gain a more complete understanding of workplace risks. For example, measurement of airborne dusts or airborne solvent vapours may demonstrate the potential for chemical absorption and subsequent adverse effects. However, workers differ in their work rate and respiration rate and consequently the amount of chemicals they inhale. This chapter introduces the concepts, advantages and drawbacks of using biological monitoring methods as complementary strategies to airborne chemical monitoring methods. Biological monitoring is the measurement of chemicals or their metabolites in fluids or tissue samples obtained from workers. Biological-effect monitoring represents the measurement of changes in biochemistry, chromosomes, or other physiological functions in the subjects being investigated.

8.2 BIOLOGICAL MONITORING

Biological monitoring can be an effective tool in risk assessment. It is widely used overseas but less so in Australia. It can be applied to both occupational and environmental exposure settings. It allows individual exposure patterns to be examined, including the contribution of specific work duties. Compliance with exposure standards and with specific workplace operating procedures can be determined, and the effectiveness of interventions designed to reduce exposure can be assessed.

In some cases, such as industries where workers are exposed to lead, measurement of blood lead concentrations or urinary markers of lead absorption and effect may be legislative requirements. In other cases, biological monitoring programs provide additional information to H&S practitioners of the exposure and absorption patterns of chemicals. Further application of biological and biological-effect monitoring in research and development may rely on the cooperation and support of H&S practitioners. Some of these more experimental approaches are described later in this chapter.

Where do biological monitoring approaches fit relative to other H&S strategies? The list below outlines some of these strategies in increasing order of relevance to occupational disease:

1. **Airborne monitoring**—measures potential or actual exposure, but does not allow measurement of individual absorption, tissue distribution and excretion of chemicals; does not allow for individual susceptibility to chemical effects.
2. **Biological monitoring**—allows an estimate of body burden, taking into account individual work practices; may enable the routes of exposure to be determined; provides some evidence of compliance with exposure and safety standards.
3. **Biological-effect monitoring**—indicates that sufficient exposure has occurred to cause a change in function of cells or tissues; it takes into account individual susceptibility; may also be applied to non-chemical exposures (e.g. ionising radiation). Intervention in the workplace that results in a decline in the measured index suggests a reduction in risk.

4. **Health surveillance**—allows the early detection of disease. This may allow an intervention to be made which will stop or reverse the disease process so that the disease outcome will be less severe than if intervention had not occurred.

8.3 IMPORTANT FACTORS IN BIOLOGICAL MONITORING

Biological monitoring is not simply a case of obtaining a random urine or blood sample from workers, introducing it into an analytical instrument, then reading results from a chart. The design of a good biological monitoring strategy requires several factors to be taken into account to ensure that appropriate conclusions can be drawn. These factors include:

- selection of the tissue or fluid to be sampled
- use of a particular analytical method
- use of an appropriate sampling regime
- identification of a suitable standard, guideline or other benchmark with which results may be compared.

8.3.1 SELECTION OF TISSUE TO BE SAMPLED

This activity may be influenced by the pharmacokinetics of the chemical concerned, ethical considerations and the convenience for investigators.

- **Pharmacokinetics**—which tissues do chemicals enter through and concentrate within? For example, chemicals eliminated in bile may not be adequately detected in a urine specimen, or fat-soluble pesticides may not be well characterised in blood.
- **Ethics**—while samples of urine and saliva may be considered non-invasive, venous blood sampling requires a consideration of the balance between the discomfort experienced by the donor and the benefits that donors accrue as a result of the procedure. Similarly, a single blood sample may be considered acceptable, but some investigations rely upon repeated blood samples, taken at intervals of days or less, to follow the time course of appearance, accumulation or elimination of workplace chemicals, and these procedures must be judged on the quality of the data obtained. In addition, blood sampling requires qualified nursing or medical assistance, including contingency plans to deal with subjects who faint, feel unwell or experience sustained bleeding. Blood, urine or other samples from unscreened subjects may also pose a risk of infection to staff performing sampling and subsequent analysis, so sampling and analysis protocols must address this issue. Although sampling and analysis for workplace investigations using biological monitoring requires the consent of the worker, research studies must usually be assessed by an institutional ethics committee with authority to approve the sampling procedures.
- **Convenience**—in some cases, investigators may obtain samples that are 'easiest' for them to collect and which are more amenable to storage prior to later analysis.

While this consideration should be seen as the lowest priority when establishing a sampling and analysis program, the sampling method selected must also be consistent with the aims of the study and the rigour of the data that may be obtained.

8.3.2 EXAMPLES OF TISSUES AND FLUIDS COMMONLY USED IN BIOLOGICAL MONITORING STUDIES

Although blood sampling is invasive, blood is one of the most often sampled tissues, since it is readily accessible. There is also a large body of accumulated data that has been published relating to blood samples collected from workers in a wide range of industries. Chemicals such as solvents, metals, pesticides and gases have all been measured in blood samples.

- **Hair sampling** has been used mostly for analysis of metals that are deposited in the hair shaft as it grows. It may represent a combination of ambient and biological monitoring, since metals in the diet and those deposited on the outer surface of the hair may also be included in the analysis. Analytical protocols may include rigorous washing procedures to minimise external deposition.
- **Exhaled air** is usually used for volatile compounds, such as solvent vapours. These may be collected in impervious containers, such as Tedlar® bags, whose contents may be injected directly into analytical instruments or concentrated in resin tubes.
- **Testing of saliva** has been used as a non-invasive procedure to analyse a variety of chemical exposures, including metals, although to date it has met with limited success and is still under development (Hardcastle et al. 2002; Timchalk et al. 2004).
- **Urine** is the most commonly collected fluid. It is easy to collect, and collections before and after work allow determination of workplace contribution to the measured index. Sampling may be repeated throughout the work week to follow time courses of chemical appearance and elimination, and to identify specific duties associated with increased chemical absorption. It has also been used for a large range of chemicals and their metabolites, ranging from solvents and gases, to metals, pesticides, plastics and others.

When using urinary concentrations of chemicals as an index of exposure, however, it is important to recall that urine may be more or less diluted depending on a variety of physiological and environmental factors. This may affect the interpretation of data collected, so it is common practice to adjust the reported concentration of analytes for the urine dilution factors. This is usually done by adjusting the specific gravity of urine to a standard specific gravity (usually 1.020) or by expressing the results relative to creatinine concentration. Creatinine, a by-product of muscle action, is filtered in the kidney and excreted in urine at a relatively constant rate.

Let us take as an example two workers who are both exposed to trichloroethylene (TCE). Their exposure can be assessed by measuring trichloroacetic acid (TCA) in urine. The workers each provide a single urine sample at the end of their shift, late in the afternoon at the end of a work week, which yielded the following results:

Worker A—90 mg TCA/L
Worker B—120 mg TCA/L

It appears that worker B has the higher exposure to TCE. However, with spot urine samples we do not know the total volume of urine passed, nor the extent of dilution of each sample. Creatinine concentrations in our example are:

Worker A—0.6 g creatinine/L
Worker B—2.4 g creatinine/L

Now, expressing TCA relative to creatinine:

Worker A—90/0.6 = 150 mg TCA/g creatinine
Worker B—120/2.4 = 50 mg TCA/g creatinine

It is clear from this that worker A has absorbed more TCE than worker B.

8.3.3 ANALYTICAL METHODS

We must identify the analyte we wish to examine as an indicator of exposure to the workplace chemical of interest based on its metabolism. Then we must select an appropriate analytical method. This will be determined primarily on the basis of whether a specific test for one or a few analytes is used, or a non-specific test that quantifies a type of analyte.

8.3.3.1 Specific analytical tests

First we decide whether to select parent chemicals or their metabolites. For example, styrene exposures may be measured by phenylglyoxylic acid (PGA) or mandelic acid (MA) in urine, or by styrene in blood. Benzene exposures may be determined by measuring phenol or S-phenylmercapturic acid in urine. It is a strength of this approach that we have specific information about chemical exposures, but where workers are exposed to both styrene and benzene, analysis of only metabolites of styrene will not yield information about benzene exposures, and vice versa.

8.3.3.2 Non-specific analytical tests

Some techniques reflect exposure to a wide variety of chemicals. For example, urinary thioethers are a type of metabolite derived from a metabolic pathway common to a wide range of chemicals. The principle of the test is that urinary thioethers (bearing a sulphur atom, or -S- group) are hydrolysed to yield thiol (-SH) which is measured using a colorimetric reagent. Hence, all thiol products are reported following hydrolysis. This test has been useful as a screening tool to assess exposures to chemicals in a wide range of industries such as petroleum refining and retailing, waste incineration, fibreglass manufacture and bitumen road construction. Care should be taken in applying this test as confounding factors contributing to elevated thioethers in urine include diet and exposure to other substances which are metabolised through the same thioether-generating pathway (e.g. eating some vegetables and smoking cigarettes both increase the urinary thioether output).

8.3.4 SAMPLING REGIME

When should we sample? An understanding of the pharmacokinetics of the chemical concerned is required to determine an appropriate sampling regime. The most important characteristic here is the elimination half-life of the chemical being measured. This is defined as the time taken for the concentration of the chemical in the blood to fall by 50 per cent. Chemicals with a short half-life are rapidly eliminated between work shifts and are unlikely to accumulate in the body with repeated exposures. Chemicals with a long half-life are eliminated slowly and a significant amount may remain in the body at the start of the next exposure period. This results in accumulation of the chemical over time. As a consequence, chemicals of short half-life (under 3 hours) must be sampled within a very short time of the exposure before blood or urine concentrations fall significantly. This is usually at the end of the daily work shift. These data usually represent only recent exposures. Chemicals with a longer half-life (3–20 hours) may be sampled at the end of the week of work shifts, and the measured index reflects exposure over a week or more. Chemicals with half-lives that are very long (weeks to years) may be sampled at any time, as the measured index reflects long-term exposures.

8.3.5 STANDARDS WITH WHICH BIOLOGICAL MONITORING DATA MAY BE COMPARED

Once we have obtained an estimate of the concentration of chemical in urine, blood or other tissue, we must draw a conclusion about the extent of exposure that was responsible for this measurement. There are two main types of standard. The Biological Exposure Index (BEI®), developed by the American Conference of Governmental Industrial Hygienists (ACGIH®), is used predominantly in the United States, Australia and the United Kingdom, while the Biological Tolerance Value (*Biologischer Arbeitsstoff Toleranz-Wert*, or BAT) is used mainly in Germany. Each requires a different approach and interpretation. BEIs® applied to Australian workplaces are published by the National Occupational Health and Safety Commission, together with a guidance note to assist in their application (NOHSC 1995a; 1995b).

8.3.5.1 Biological exposure index (BEI®)

The BEI® is estimated from the relationship observed between a particular biological monitoring measure (such as urinary chemical concentration) and the corresponding airborne chemical concentrations (see Figure 8.1a). It indicates the expected biological monitoring value if worker exposure occurs at about the exposure standard (ES) (see Figure 8.1b). However, because of the variation in the values used to construct the relationship between airborne and urinary chemicals, some workers exposed at or above the ES may be found with a urinary chemical level below the BEI®. Hence, workers may still be at risk of overexposure even if they are found with a urinary chemical level below the BEI®.

8.3.5.2 Biological tolerance value (BAT)

The BAT is a more conservative estimate than the BEI® and aims to represent an upper limit or ceiling value for biological monitoring estimates above which overexposure is considered to have occurred. Figure 8.1c illustrates that workers whose airborne exposure approaches or exceeds the ES also exceed the BAT, suggesting the BAT has good predictive value. However, the BAT may be overly conservative, being exceeded by some workers not exposed to levels above the ES, and hence not necessarily at risk.

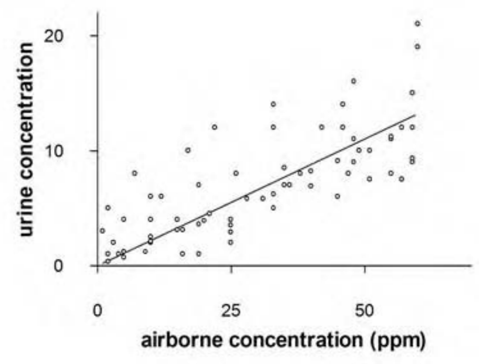

Figure 8.1a Relationship between concentration of a chemical in worker urine and air

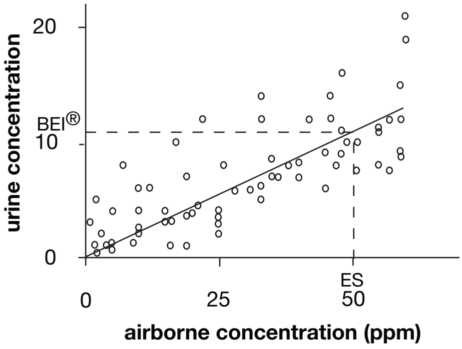

Figure 8.1b Estimation of BEI® from ES

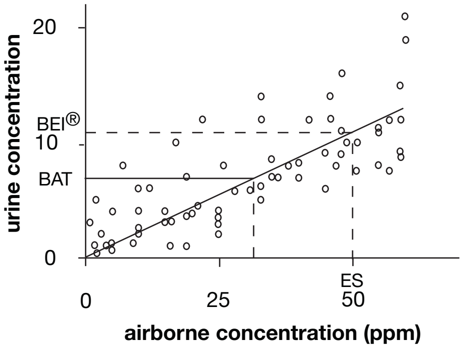

Figure 8.1c Estimation of BAT

8.3.5.3 Other individuals and groups

Workplace exposure standards are published for over 440 chemicals in Australia, of which only 40 or so have a published BEI® (NOHSC 1995b). Hence in many workplaces there may not be a BEI® with which biological monitoring data may be compared. In these cases, relative levels of exposure can be determined by comparing individual workers or groups of workers. This is particularly useful when workers may be grouped according to similarity of duties or potential exposures, allowing the relative contribution of these exposures to chemical absorption to be determined. Similarly, the effectiveness of interventions and controls may be examined by biological monitoring strategies using before-and-after designs. Group comparisons are particularly useful when non-specific chemical assays are used, since individual values may be too variable to allow meaningful interpretation.

8.3.6 OTHER ADVANTAGES OF BIOLOGICAL MONITORING

Biological monitoring allows measurement of dermal exposure, oral exposure and respiratory exposure combined, since we cannot discriminate the source of exposure simply from a urine or blood sample. However, suitable study designs may be developed to allow discrimination of sources. For example, workers exposed to styrene were evaluated for blood styrene concentrations and were then provided with gloves or a respirator, both gloves and a respirator, or neither. Blood styrene concentrations were highest in unprotected workers, and concentrations were little changed by the provision of gloves. Maximum protection was achieved with both gloves and a respirator, and similar protection occurred when wearing a respirator alone. These data suggested that the main source of exposure to styrene was by inhalation, and that interventions should be targeted to reduce this component (Brooks et al. 1980).

Biological monitoring is gaining more use in epidemiological studies to classify workers by levels of exposure prior to investigating disease outcomes. This provides independent confirmation of exposure groupings when establishing links between chemical exposure and disease, reducing the likelihood of misclassification bias.

8.4 BIOLOGICAL-EFFECT MONITORING

Biological-effect monitoring allows the examination of particular cell or tissue endpoints that indicate some response to workplace chemical exposure. Biomarkers are now considered by many to be early indicators of effects, including adverse effects. The distinction between measuring some early biomarkers of disease and carrying out health surveillance is not always clear.

8.5 EXAMPLES OF COMMONLY USED BIOMARKERS OF EFFECT

Biological-effect monitoring usually refers to a variety of assays based on biochemical or chromosomal changes, or changes in the amount or character of particular proteins, enzymes or nucleic acids. The following examples are not exhaustive, and newer methods continue to be developed. Few are yet in routine use by H&S practitioners, although as they are validated they may gain greater acceptance.

8.5.1 BIOCHEMICAL METHODS

Biochemical methods include measures of enzyme activities that are either inhibited or enhanced (induced) by chemical exposure. Organophosphorus insecticides exert their principal toxic effect by inhibiting the enzyme acetylcholinesterase in the central and peripheral nervous systems. Similar enzymes in blood (serum cholinesterases and erythrocyte acetylcholinesterase) are also inhibited, and the activity of these can act as a measure of the effect of the exposure in the central nervous system. Lead inhibits several key enzymes involved in the synthesis of haemoglobin. This can be detected by measuring the accumulation of some of the haem precursors, such as d-aminolaevulinic acid (d-ALA) or porphyrins in urine and/or blood (see Chapter 6, Metals, Section 6.7).

Organochlorine insecticides and petroleum fuels have both been shown to increase the activity of liver enzymes (Edwards & Priestly 1993; 1994). While enzyme induction may not itself be defined as a toxic effect, it is an adaptive response to exposure. The consequences may include enhancement of the metabolism of medications (making them less effective in exposed subjects) or the increased formation of toxic intermediate products from other chemical exposures.

Some enzymes measured in blood may indicate tissue-specific damage. For example, the enzyme alanine aminotransferase is found within liver cells and is not normally found in blood. Liver damage associated with some chemicals causes an increase in the blood concentration of this enzyme. However, since the increase in circulating enzyme reveals frank damage to liver tissue, it may better be described as a health surveillance method.

8.5.2 EMERGING MEASURES OF DAMAGE TO DNA

Some occupational chemical exposures are known to cause cancer. Many of the chemicals shown to cause cancer have been shown to be genotoxic—that is, they interact directly with DNA. In most cases, the damage to DNA is repaired but the repair process itself may be 'error prone', resulting in cellular changes that may give rise to cancer or other disorders. Genotoxicity tests are largely derived from *in vitro* and animal experimental methods but have been adapted to examine DNA and chromosome damage in humans. As a result, their direct relevance to disease outcomes in humans may not be clear or easy to interpret. The methods used in occupational studies include cellular mutation, chromosome aberration and DNA strand breaks.

Adducts, or addition products, represent the direct interaction of chemicals with cellular target molecules, such as DNA or protein. The amount of adduct present in samples is an estimate of the dose of chemicals reaching critical cellular targets, so is possibly more closely related to biological monitoring than to biological-effect monitoring approaches. Oncoproteins have been shown to be important in the development of cancer, and are coded by oncogenes. The activity or expression of specific oncogenes and the appearance of particular oncoproteins are thought to reflect cancer risk, and have been investigated in a variety of occupations (e.g. foundry workers), in groups of workers with specific chemical exposures (e.g. to vinyl chloride) and in populations living in industrial areas.

Further reading on developments in this area is listed in Section 8.10.

8.6 IMPORTANT FACTORS IN BIOLOGICAL-EFFECT MONITORING

Biological-effect monitoring requires several factors to be taken into account, similar to those important in biological monitoring procedures, including the selection of appropriate tissues, the specific test to be used, the sampling regime, and how data will be interpreted.

8.6.1 SELECTION OF TISSUE TO BE EXAMINED

Tissues used as indicators of effect must be responsive to the chemicals of concern. However, sometimes the true target tissue, that is, the tissue relevant to the disease outcome, is inaccessible (such as the liver or other organs) or difficult to sample (such as bone marrow), so it is also important to consider whether the selected tissue responds in a similar way to the target tissue. This may rely partly on the pharmacokinetics of the chemical (does it reach the sampled tissue?) and partly on the qualitative nature of the response in the tissue. Again, ethics are important, as some of the sampling procedures are highly invasive (such as blood sampling, collection of bone marrow), may be distasteful to the subjects, or may involve some risks of discomfort or injury. The convenience of sampling for both the investigator and the subject must also be considered, especially where repeated samples are required to be collected. In these cases, peripheral tissues such as blood or urine are most suitable.

8.6.2 METHOD SELECTION

What criteria must we consider to help us decide the preferred tissue to be sampled and analysed in a biological-effect monitoring study? The first consideration is to use the tissue defined for published BEI® or BAT standards, where they exist. In research studies, tests that have previously been applied to occupational exposures and for which some comparative data are available are preferred. Tests shown in animal and *in vitro* studies to respond to the chemical of interest, and tests for which a reliable method is or can be established, are often the basis for new methods in biological-effect monitoring.

Next we need to consider whether the endpoint we are measuring should be a specific or non-specific index of chemical exposure. Specific measurements include the measurement of lead exposure by measuring d-ALA or coproporphyrin in urine, exposure to organophosphorus (OP) compounds by the inhibition of cholinesterase enzymes. Even these have more recently been shown to be not entirely selective (haem synthesis is also inhibited by some pesticides, and cholinesterase enzymes by some metals). However, the strength of non-specific tests (e.g. chromosome analysis or cellular mutation) may also rest on their indication of exposure to many chemicals from both occupational and environmental sources.

8.6.3 SAMPLING REGIME

The time course of appearance and decline of the biological-effect monitoring endpoints is critical in the interpretation of the time course of exposure and the likely duties that contribute to it. For example, cholinesterase measurements in blood samples reflect relatively recent exposures to OP insecticides, but the effect is long-lived. A single exposure to OP will result in cholinesterase depression that recovers at the same rate as the production of new enzyme (with full recovery of enzyme function after about 10 weeks). Some chromosome aberrations persist in cells for 6 months or more.

Ideally, examination of biological-effect markers should be performed before and after commencing duties involving chemical exposure, or before and after interventions designed to reduce them.

8.6.4 STANDARDS

How do we interpret these data? Standards with which results may be compared generally do not exist, with inhibition of the lead biosynthetic pathway, and inhibition of cholinesterase enzymes by OP pesticide exposure being significant exceptions. For example, clinical symptoms are often seen with OP pesticide exposures when cholinesterases are inhibited by 70–80 per cent. Generally, results may be used for comparison before and at intervals after employment, or with other individuals and groups with different duties or different degrees of potential exposure.

8.6.5 OTHER ADVANTAGES OF BIOLOGICAL-EFFECT MONITORING

Biological-effect monitoring provides independent confirmation of whether workplace exposures result in changes to physiological or biochemical function, even where workplaces comply with the relevant ES. This may suggest that any exposure resulting in these changes is undesirable, and that workplace procedures and conditions should be changed to reduce exposure further. It also allows us to question whether the ESs are valid and appropriate, and may provide evidence to suggest that a particular ES should be reviewed. In some specialised cases, monitoring effects may indicate that exposures are sufficiently high to require the initiation of medical therapy or support (e.g. with cholinesterase enzymes depressed more than 70–80 per cent). Effects are more likely to be seen in workers who are the most susceptible to them. Hence, where the ES is designed to protect 'nearly all workers' who are repeatedly exposed to chemicals, biological-effect monitoring approaches provide evidence to protect workers who are potentially more vulnerable to the harmful effects of chemicals, due to pre-existing health conditions, general health status or genetic variability.

While most of the discussion here has focused on biological-effect monitoring applied to chemical exposures, some physical hazards may also be assessed using these techniques. In particular, the tests evaluating genotoxic or chromosome damaging effects may be applied to ionising and non-ionising radiation, noise, and perhaps some other hazards.

8.7 BIOMARKERS OF SUSCEPTIBILITY

Biological monitoring techniques may be used to identify susceptible individuals. For example, the ratio of the activities of two blood enzymes, paraoxonase and arylesterase, may be used to determine potential susceptibility to the toxic effects of organophosphorus insecticides. A high paraoxonase/arylesterase ratio suggests more rapid metabolism of OP compounds and greater resistance to adverse effects. A low ratio suggests a greater risk of adverse effect following exposure. Similarly, low activity of the enzyme N-acetyltransferase is implicated in the development of bladder cancer in workers exposed to aromatic amines. The development of these indicators, and their use in pre-employment screening and workplace exclusion practices, is beyond the scope of this book. For further details see the Australasian Faculty of Occupational Medicine (AFOM) monograph listed in Section 8.10.

8.8 CONCLUSIONS

This chapter has reviewed the application of biological monitoring and biological-effect monitoring methods to the evaluation of worker exposure and risk. While these approaches have many strengths, their major weakness is that it may be more difficult to interpret biological monitoring data. Biological monitoring techniques may be affected by variations in exposure, by metabolic variations in individuals, by competition by other substrates for the metabolic pathway, by saturation of enzymes at high concentrations, by protein binding of chemicals in blood and tissues, by fat/muscle composition, or by pre-existing disease conditions. It may require expert assistance to ensure that the appropriate conclusions are drawn in these assessments.

It may also be difficult to communicate the results obtained to employers and workers in a way that they can integrate them into their workplace practices. For example, airborne chemical monitoring may yield data indicating that the workplace either complies or does not comply with exposure standards. Workers and managers may simply be advised that airborne concentrations must be reduced. Workers with concentrations of urinary metabolites that exceed a BEI® or BAT may be advised that they have a high exposure and absorption of workplace chemicals, and that these will decline if exposure is reduced. However, a worker who is advised of an elevated chromosome aberration frequency in his or her blood cells may not be equipped to interpret that information sensibly, although they may understand that they may have greater exposure than their colleagues or may be more susceptible to chemical effects. This may provide sufficient motivation to change behaviours or work practices.

This chapter has described not only those methods that are more commonly used in biological monitoring, but also some that have been used predominantly in research studies rather than in occupational health practice. Sometimes H&S practitioners may themselves become involved in these research studies, so it is important that they are familiar with not only the principles behind these tests, but also their strengths and weaknesses when applied to workplace situations. These emerging methods and technologies may represent tools that provide further information relevant to workplace exposure assessments.

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9. Indoor air quality

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9.1 INTRODUCTION

Poor indoor air quality (IAQ) can be a significant health, environmental and economic problem, and has become a public health and liability issue for employers and building managers. The meaning of IAQ is often interpreted differently across disciplines, but this chapter uses a broad definition for IAQ: 'the totality of attributes of indoor air that affect a person's health and wellbeing'. IAQ evaluation must thereby determine how well indoor air: satisfies thermal and respiratory requirements of occupants; prevents unhealthy accumulation of pollutants; and allows for a sense of wellbeing. In addition to occupant health and wellbeing, IAQ can directly impact the personnel costs of any business, since research findings show an association with occupant productivity.

Research in most developed countries has established the occurrence of a range of **building-related illnesses**, many with identifiable causes (e.g. legionnaires' disease, caused by bacterial growth in cooling towers). A subset of building-related illnesses—termed the 'sick building syndrome' (SBS) by the World Health Organization (WHO 1982)—includes mainly subjective symptoms (mild irritation of eyes, nose and throat, headaches, lethargy). SBS symptoms are believed to arise from multiple causes which, while not clearly understood, are associated mainly (but not exclusively) with air-conditioned office buildings. Australian studies have been limited, but indicate patterns similar to other developed countries for building-related illnesses, SBS-like symptoms and dissatisfaction with office air environments.

Sectors of the population differ markedly in their sensitivities to pollutants. Infants and children are more vulnerable to respiratory illnesses associated with environmental tobacco smoke, house dust mites and gas combustion products such as nitrogen dioxide. Asthmatics are sensitive to a variety of pollutants which act as inducers and triggers. The existence of multiple chemical sensitivity and a possible influence from indoor air pollutants are under debate. The protection of sensitive sectors of the population is considered appropriate when selecting IAQ indicators for residential, health and educational building categories. Indicators for other building categories need to consider the likely access by sensitive sectors of the population, as for example with an office building which is accessible to the public. While this chapter is directed at H&S practitioners who will deal primarily with non-residential buildings, they will need an understanding of IAQ impacts in residential buildings as well, since these are relevant to sensitive population sectors and to work-at-home practice.

A large number of pollutants have been investigated in Australian buildings, some in great detail while for others few observations are available, as summarised in Table 9.1. Few pollutants have been sufficiently researched to determine exposure levels for the Australian population or the most appropriate strategies to reduce exposure (Brown 1997). Major **indoor air pollutants** (those of indoor origin) typically occur at much higher concentrations than air pollutants found outdoors, or are completely different from those occurring outdoors. Outdoor air pollutants (e.g. fine particles, ozone) will reach indoors with ventilation air, but generally at reduced concentrations (apart from gases such as carbon monoxide and carbon dioxide) due to deposition or losses on building surfaces. The pollutants that originate indoors can increase to very elevated concentrations compared to outdoor pollutants, because of

Table 9.1 Pollutants measured in Australian buildings (some relative to NHMRC 1989 goals)

Pollutant	Indoor concentration levels	Major sources	Control
Asbestos fibres	<0.002 fibres/ml	Friable asbestos products	Risk management, removal
Radon: conventional dwellings	99.9% < goal of 200 Bq/m^3	Soil under building	Siting of building
Radon: earth-constructed dwellings	~9% > goal of 200 Bq/m^3	Background radon from earth walls	Material selection
Environmental tobacco smoke (ETS)	High in recreational buildings	Cigarette smoke	Prohibition of smoking, designated smoking area
Respirable particulate matter	Poorly characterised	ETS, cooking, fuel combustion	Poorly characterised
Legionella spp.	30% of population exposed	Water cooling towers	Maintenance, site selection
House dust mites	10–40 µg/g Der p1 allergen in house dust	Allergen build-up in bedding, carpet, furniture	Removal of habitats, humidity control
Micro-organisms (CFU = colony forming units)	100–18 000 CFU/m^3	Moist/damp surfaces	Control moisture/mould
Formaldehyde: conventional buildings	<100 ppb (1–3 day average) (goal = 100 ppb ceiling)	Reconstituted wood-based products	Source emission control, ventilation
Formaldehyde: mobile buildings	100–1000 ppb	Reconstituted wood-based products	Source emission control, ventilation
Volatile organic compounds (VOC):			
• established buildings	Total VOC < 500 µg/m^3	'Wet' synthetic materials (adhesives, paints), office equipment, printed matter, furniture	Source emission control, ventilation
• new buildings	Total 2000–20 000 µg/m^3 (goal 500 µg/m^3)		
Pesticides	Limited data, median < 5 µg/m^3	Major sources unknown	Floor structure, clean-up, inspection
Nitrogen dioxide	Up to 1000 ppb	Unflued gas heaters and stoves	Source emission control, flued appliances
Carbon monoxide	~10% > goal of 9 ppm	Unflued gas heaters and stoves	Source emission control, flued appliances
Carbon dioxide	Poorly characterised	Exhaled air	Ventilation to Standards
Ozone	Poorly characterised	Office equipment, ozone deodorisers	Source emission control, ventilation

high pollutant emissions from multiple indoor sources under conditions where air dispersion is restrained (even if the ventilation is in compliance with building codes). Since people generally spend around 90 per cent of their time indoors, building occupants are exposed to much higher concentrations of indoor air pollutants, and for longer exposure times, than of outdoor pollutants.

In Australia, the most significant IAQ pollutants are considered to be:

- environmental tobacco smoke in hospitality buildings, house dust mites and nitrogen dioxide (all based on the observation of high indoor levels)
- respirable particulate matter, micro-organisms, volatile organic compounds and formaldehyde (based on their potential for high indoor levels under specific conditions).

High levels of environmental tobacco smoke have been found in hospitality buildings since mechanical ventilation systems are not capable of adequately removing this pollutant. Smoking is now prohibited in commercial buildings, and problems in such buildings are limited to odours and incidental smoke ingress when occupants step outdoors to smoke while remaining close to doorways or air intakes. House dust mite allergen levels are very high in residences (and probably some childcare facilities and schools) in coastal regions and may present a particular health problem for Australia since the greater part of the population lives in coastal cities. Nitrogen dioxide concentrations have been found to be high in many residences and schools with **unflued** domestic gas heaters. While heater rectification programs have commenced for government schools in New South Wales, a vast number of these heaters are used with little control in most other states and the territories. Additionally, unflued industrial gas heaters are sometimes used in large buildings (e.g. shops, warehouses) and may cause high indoor air pollution.

The ventilation rate and the thermal comfort of a building space must also be considered key factors affecting IAQ. Low ventilation rates will cause odours from occupants and pollutants from indoor sources to accumulate, reducing IAQ. This factor is regulated for Australian buildings at construction through the building code, but subsequent control is not regulated. Also, while code requirements have changed over time they are not retrospectively applied to existing buildings. **It is advised that the ventilation rate be assessed relative to the current building code as the first step in any IAQ investigation.** The thermal comfort of occupants is important to their acceptance of building spaces but involves a complex range of factors (related to both the building and the occupant); while international thermal comfort guidelines exist, these are not regulated in building codes.

This chapter describes what constitutes acceptable IAQ, the status of IAQ in Australia and what has influenced this status, what regulations and standards exist, and how to investigate indoor air problems with a view to their control.

9.2 ASSESSMENT OF IAQ

The following indicators (and their critical sources where applicable) are recommended for IAQ assessment and control (refer to Brown 1997 for specific details):

- Comfort indicators:
  - thermal comfort criteria
  - optimal humidity range 40–60% RH (relative humidity)
  - occupant symptom questionnaire (Raw 1995).
- Ventilation indicators:
  - concentration of carbon dioxide under steady-state conditions: residences <1000 ppm, commercial buildings <800 ppm
  - mechanical ventilation system to current Australian Standards® requirements.
- Source indicators:
  - asbestos fibres: applicable codes and regulations for hazard assessment of products
  - radon: measure for earth-constructed residences or habitable basements in relation to NHMRC (1989) goal
  - environmental tobacco smoke: use nicotine or respirable particulate matter as indicators for areas with heavy smoking; use combustion-derived particulates (ASTM 2002) for any smoking area
  - respirable particulate matter (RPM): compare to National Environmental Protection Measures for $PM_{2.5}$ and PM_{10} (particulate matter with sampling cut points of 2.5 µm and 10 µm, respectively; the cut point is the particle aerodynamic diameter at which the efficiency of particle capture is 50%)
  - *Legionella* species: use current codes and regulations
  - house dust mite: measure allergens in dust to determine if below tenth percentile level for particular geographical area
  - micro-organisms: moist or damp surfaces, with or without visible growths present, are unacceptable; no presence of confirmed pathogens or toxigenic fungi in air or surface samples
  - formaldehyde: measure in relation to NHMRC (1989) goal (or more recent goals such as NICNAS 2005) in new buildings and in caravans or transportable buildings with other than small usage of reconstituted wood-based products
  - volatile organic compounds (VOCs): a total VOC concentration >500 µg/m^3 indicates significant sources to be present (NHMRC 1993); assess health significance of concentrations of carcinogens and irritants if potential sources are present
  - pesticides: measure concentrations if visible residues are found or if building has 'leaky' floor, especially for post-construction application of termiticides
  - nitrogen dioxide: measure in relation to the National Environmental Protection Measure in all buildings (but particularly dwellings, schools and hospitals) while unflued gas appliances are operating (particularly heaters)
  - carbon monoxide: measure in relation to NHMRC (1989) goal in all buildings (but particularly dwellings, schools and hospitals) while unflued gas appliances are operating (particularly heaters), and in relation to workplace exposure standard in enclosed parking sites
  - ozone: measure in relation to NHMRC goal in rooms with heavy use of electrostatic photocopiers, laser printers and other sources, and at outlets from ozone-based air sterilisers.

9.3 WHAT IS IAQ AND WHO IS RESPONSIBLE?

9.3.1 DEFINITION OF IAQ

It is important to be clear on what you or others may mean when discussing IAQ. To an engineer it may mean the building's ventilation rate; to an architect, the occupants' perceptions of the building; to a microbiologist, the level of spores from plants, moulds, etcetera; to a hygienist or toxicologist, the exposures to specific pollutants; and so on. So first we need to break down the term to its constituents:

- indoor—an enclosed space that offers human shelter
- air—what we breathe to provide oxygen, and to provide heat and moisture transfer to/from our bodies
- quality—a characteristic that distinguishes something.

From the viewpoint of human activities, we essentially inhale either air within buildings or air that is outdoors. Simplistically, these should be very similar since outdoor air is used to ventilate buildings and variations in outdoor air quality (e.g. from traffic pollution) should be reflected in indoor air. However, this is far from the case because we generate a wide range of pollutants within buildings from our activities and from the materials and appliances that we use, essentially adding extra pollutants to those introduced from outdoor air. The significance of this is enhanced by the fact that most urban populations spend 91 per cent of their time indoors, 5 per cent in travel and 4 per cent outdoors (see Section 9.8).

In Australia, there have been two definitions for 'indoor air' provided by the NHMRC (1989; 1993):

- Any enclosed space where people spend **1 hour/day** or more (note that this means the 'in travel' component of time can be classified as indoor air).
- The air in **non-industrial** buildings (or parts thereof) such as **dwellings**, **offices**, **schools** and **hospitals**.

Indoor air definitions generally exclude industrial buildings, probably because these are well controlled by OH&S regulations. Conversely, however, the OH&S regulations provide poor guidance for IAQ in non-industrial workplaces. Clearly there must be some account of all air pollutant exposures (within a total exposure concept) if the health effects of a pollutant exposure are evaluated. Also, distinctly different from the industrial scenario with its well-known 'healthy worker effect', the IAQ definitions appear to be aimed at protecting the general population, which includes sensitive people with existing illnesses, and the young and the elderly. Lastly, while an industrial building environment may have a few pollutants and a limited period of exposure (typically 40 hours/week), indoor air exposures can be to a diverse range of pollutants at nearly continuous exposure. This causes a dilemma for the H&S practitioner, who may apply a workplace exposure standard (ES) in a factory but not in an office building. One approach for dealing with this problem (Emmet 1994) is to apply an

ES for an office where the general public cannot enter and an IAQ goal (described in Section 9.3.3) for an office accessible to the general public. In general, however, ESs are set at levels much greater than would be tolerated by many office workers (especially the more sensitive groups), and so this approach has limited scope. Clearly, the protection of sensitive sectors of the population is appropriate when selecting indoor air quality indicators for residential, health and educational buildings. There is probably no single answer to selecting appropriate criteria for assessment and control, other than to consider again what our definition of IAQ is and what we aim to achieve for acceptable IAQ. This is encompassed in the definition given by Environment Australia (2001): **IAQ is the totality of attributes of indoor air that affect a person's health and wellbeing**. IAQ attributes can mean pollutant levels, air temperature and humidity, air velocity, odours, etcetera, either individually or in combination if interactive. The inclusion of wellbeing rather than just health recognises that occupant perception of the air quality will significantly affect his or her response to that environment, the acceptance of it, and the delivery of productive outcomes within that environment. Also, this definition incorporates the concept of health used in the Constitution of the World Health Organization (WHO): 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO undated).

9.3.2 REGULATION

Regulation of indoor air quality is limited, especially in comparison to the regulation of outdoor air quality and industrial workplace air, a situation that also existed in other countries until the early 2000s, when several countries (Finland, Netherlands, Germany, Japan and China) initiated IAQ regulations. While Australian guidance has been provided by authorities such as the National Health and Medical Research Council (NHMRC) and the National Occupational Health and Safety Commission (NOHSC), there is a need for a more structured approach for evaluation and control of IAQ. A severe limitation is the absence of a single government authority with responsibility for indoor air quality. Harmonisation of occupational standards and environmental guidelines is desirable in order to clarify their roles in different indoor environments. Development of improved ventilation codes, voluntary reduction of pollutant emissions from manufactured products, and improved public education should be used to improve indoor air quality.

9.3.3 RESPONSIBILITY FOR IAQ

The responsibility for IAQ falls to environmental or health agencies in many developed countries, and sometimes to building authorities. For example, the US Environmental Protection Agency carries out extensive research and industry/community activities. The WHO (2000) established Air Quality Goals for Europe, which stated clearly that they were relevant to both indoor and outdoor environments. In Australia, state environment agencies have had limited involvement with IAQ measurement (Ferrari 1991; Environment Protection Authority 1993; Brown 1997; Newton et al. 2001).

In recent years, Environment Australia (2001) and the Department of Health and Ageing (DHA 2002; 2004a; 2004b) have undertaken IAQ research and community education activities, though no organisation has taken clear regulatory responsibility.

The Australian Building Codes Board (ABCB) regulates building practice in Australia through the Building Code of Australia (BCA), which is adopted by most states with small alterations (ABCB 2005). The BCA is performance based rather than prescriptive. Since compliance with the BCA is a legal requirement, a reference to an Australian Standard® in BCA's Housing Performance Provisions adopts that standard as a legal requirement. In relation to IAQ, the Australian Standards® AS 1668.2 *Mechanical Ventilation for Acceptable Indoor Air Quality* (Standards Australia 1991) and AS/NZS 3666.1 *Air-handling and Water Systems of Buildings—Microbial Control. Part 1: Design, Installation and Commissioning* are adopted (Standards Australia 2002b). The BCA itself has a specific performance provision for IAQ, but only in relation to ventilation with outdoor air (see Section 9.6).

Historically, IAQ in Australia has been defined as acceptable according to several NHMRC goals, mostly health-based criteria which are presented as recommendations (not regulation), as in Table 9.2. There are few exposure criteria for indoor (cf. industrial workplaces) and outdoor air. In the absence of indoor air exposure criteria, regulatory criteria for outdoor air (if health based) could be considered when assessing indoor air in non-industrial buildings. For example, the National Environment Protection Measures (NEPM) for Ambient Air Quality and Air Toxics (Environment Protection and Heritage Council 1998; 2004) will require ambient air limits (Table 9.3) on the basis of their health effects.

9.4 BUILDING-RELATED ILLNESSES AND SICK BUILDING SYNDROME

Health effects that are experienced by the occupants of some buildings range from severe effects (asthma, allergic response, cancer risks) to a range of subjective symptoms, generally non-specific in nature, which exhibit an association with the indoor environment, particularly indoor air. Collectively, all such health effects are termed 'building-related illnesses', and many arise from identifiable causes such as specific pollutants (e.g. asbestos, dust mite allergen, *Legionella* species), poor ventilation, humidifier fever, poor thermal comfort, poor lighting and psychosocial factors. However, it has been found that a range of subjective symptoms, termed the 'sick building syndrome' (SBS) by the World Health Organization (WHO 1982), occur in a high proportion (30 per cent or more) of occupants of specific buildings (generally, but not exclusively, air-conditioned offices) without clearly identified causes. **A critical feature of such symptoms is their association with occupancy of the building.** Raw (1995) summarised the symptoms of SBS as follows:

- Irritated, dry or watering eyes (sometimes described as itching, tiredness, smarting, redness, burning, and difficulty in wearing contact lenses).
- Irritated, runny or blocked nose (sometimes described as congestion, nose bleeds, itchy or stuffy nose).

Table 9.2 Interim national IAQ goals recommended by the NHMRC—goals for maximum permissible levels of pollutants in indoor air (goals for radon and formaldehyde are final goals)

Pollutant	**IAQ goals**		**Measurement criteria**	**Notes**	**NHMRC session**
	$\mu g/m^3$	**ppm**			
Carbon monoxide	10 000	9	8-hour average not to be exceeded more than once a year	This period of measurement is not to be confused with that for workplace exposure standard	98th (Oct. 1984)
Formaldehyde	120	0.1	Not to be exceeded	Within domestic premises and schools	93rd (June 1982)
Lead	1.5	—	3-month average	—	88th (Oct. 1979)
Ozone, photochemical oxidants	210	0.1	Hourly average not to be exceeded more than once a year	A public warning to be given if ozone levels are expected to rise above 500 $\mu g/m^3$ (0.25 ppm)	119th (June 1995)
	170	0.08	4-hour average		
Radon gas	200 Bq/m^3 (5.4 nCi/m^3)		Annual mean	Action level for simple remedial action in Australian homes	109th (May 1990)
Sulfates	15	—	Annual mean	—	104th (Nov. 1987)
Sulphur dioxide	700	0.25	10-minute average	At these recommended levels, there still may be some (asthmatics, those suffering chronic lung disease) who will experience respiratory symptoms and may need further medical advice	120th (Nov. 1995)
	570	0.20	1-hour average		
	60	0.02	Annual mean		
Total suspended particulates	90	—	Annual mean	In conjunction with SO_2 goal	92nd (Oct. 1981)
Total VOCs	500	—	Hourly average	A single compound shall not contribute more than 50% of the total	115th (June 1993)

Source: NHMRC (1996)

Table 9.3 Ambient air NEPMs

Pollutant	Averaging period	Monitoring investigation level	Goal
Carbon monoxide	8 hours	9.0 ppm	To be met in all states and territories by 2008, with few exceedences
Nitrogen dioxide	1 hour 1 year	0.12 ppm 0.03 ppm	To be met in all states and territories by 2008, with few exceedences
Photochemical oxidants (as ozone)	1 hour 4 hours	0.01 ppm 0.08 ppm	To be met in all states and territories by 2008, with few exceedences
Sulphur dioxide	1 hour 24 hours 1 year	0.20 ppm 0.08 ppm 0.02 ppm	To be met in all states and territories by 2008, with few exceedences
Lead	1 year	0.5 μg/m^3	To be met in all states and territories by 2008, with **no** exceedences
Fine particles as PM$_{2.5}$	24 hours 1 year	25 μg/m^3 8 μg/m^3	Advisory reporting standard; to be met in all states and territories by 2008, with few exceedences
Benzene	Annual average[a]	0.003 ppm	8-year goal is to gather sufficient data nationally to facilitate development of a standard.
Benzo(a)pyrene as a marker for polycyclic aromatic hydrocarbons	Annual average[a]	0.3 ng/m^3	8-year goal is to gather sufficient data nationally to facilitate development of a standard
Formaldehyde	24 hours[b]	0.04 ppm	8-year goal is to gather sufficient data nationally to facilitate development of a standard
Toluene	24 hours[b] Annual average[a]	1 ppm 0.1 ppm	8-year goal is to gather sufficient data nationally to facilitate development of a standard
Xylenes (as total of ortho, meta and para isomers)	24 hours[b] Annual average[a]	0.25 ppm 0.2 ppm	8-year goal is to gather sufficient data nationally to facilitate development of a standard

[a] For the purposes of this measure, the annual average concentrations in column 3 are the arithmetic mean concentrations of 24-hour monitoring results.

[b] For the purposes of this measure, monitoring over a 24-hour period is to be conducted from midnight to midnight.

Source: Department of Environment and Heritage <www.deh.gov.au/atmosphere/airquality/nepm.html>

- Dry or sore throat (sometimes described as irritation, oropharyngeal symptoms, upper airway irritation, difficulty swallowing).
- Dryness, itching or irritation of the skin, occasionally with rash (or specific clinical terms such as erythema, rosacea, urticaria, pruritis, xerodermia).
- Less specific symptoms such as headache, lethargy, irritability and poor concentration.

Despite much investigation into SBS, it is now considered probable that it has multifactorial causes, with no single cause showing a clear association to the symptoms (Sykes 1989). Raw (1995) summarised the knowledge on potential causes as follows:

- **Ventilation rate**—in some cases symptoms have been reduced by increasing fresh air intake, but there is little evidence that this will be effective where the ventilation rate already meets current guidelines.
- **Ventilation systems**—air-conditioning is strongly associated with SBS but mechanical ventilation and humidification are not; the association may be due to poor air distribution, poor maintenance, or the creation of an environment conducive to growth of micro-organisms and dust mites.
- **Airborne chemical pollution**—many pollutants probably contribute.
- **Micro-organisms and particulates**—evidence is increasing that an important role is played by a mixture of organic and non-organic dust from poorly maintained air-conditioning systems and furnishings.
- **Temperature**—temperatures above 21°C have been shown to increase symptoms, but possibly only where humidity is low or under particular conditions of (low) air movement.
- **Humidity**—relative humidity below 30 per cent may be associated with symptoms.
- **Lighting**—certain symptoms may be promoted by poor lighting, the absence of windows, or flicker from fluorescent tubes operated at 50 Hz.
- **Personal and organisational factors**—symptoms are more frequent among women, workers in routine jobs, those with a history of allergy, workers at video display units, and those who perceive they have poor control over their indoor environment.

Assessment of building-related illnesses in Australia has been very limited and is restricted to studies of office environments, but indicates that dissatisfaction with office IAQ may be common. Williams (1992) reported that occupants of 62 per cent of 228 suburban, low-rise office buildings in Melbourne experienced unacceptably 'stuffy' and 'drowsy' conditions. Eighty-two per cent of the buildings failed to meet existing ventilation requirements (largely due to changes in requirements after the buildings were constructed). A multi-state survey (McKenna 1990) of 511 government office workers in 1990 found that 91 per cent experienced discomfort or illness associated with poor ventilation and temperature control. Complaints included: too hot (72%), too stuffy (72%), drowsiness (48%), headaches (48%) and sore throat (55%). Rowe and Wilke (1994) found that more than 45 per cent of occupants of eight office buildings in the Sydney CBD and suburbs were dissatisfied with either thermal comfort or indoor air quality. Dingle and Olden (1992) reported that occupants of a new four-level office building in Perth experienced dry eyes (65%), tired and strained eyes (54%), reflection/glare (41%), fatigue (57%), sore throat (28%) and migraine (36%). Rabone et al. (1994) found that work-related symptoms in 401 occupants of a 'sick' office building in Sydney were strongly associated with stuffiness of the air. Rowe (2003) found differences in occupants' perceptions of air quality, thermal comfort and their self-reported SBS symptoms in Sydney offices, with worse conditions for mechanically ventilated/air-conditioned offices compared to naturally ventilated offices. When the latter were supplied with occupant-controlled refrigerated cooling/heating units, occupants' perceptions were further improved.

The NSW Standing Committee on Public Works (2001) conducted an inquiry into SBS in Australia and concluded that it significantly impacted the health and productivity of building occupants. The Committee called for regulations and improved standards and codes for ventilation systems and their maintenance, low-emission building and fit-out materials, commissioning of new buildings, and indoor pollutant criteria for existing buildings.

9.5 RELATIONSHIP OF IAQ TO PRODUCTIVITY

Improvements in IAQ have the potential to reduce:

- costs for health care
- sick leave
- diminished performance at work caused by adverse health
- costs of investigating occupant complaints.

Thermal comfort and lighting quality may also influence worker performance without impacting health. Staff salaries dominate total costs in many organisations, and even very small percentage increases in productivity may justify expenditures for building improvements. Currently, the linkages between specific building practices, indoor environments and productivity are not well quantified. However, Fisk and Rosenfeld (1997) reviewed existing literature and developed estimates of the potential to improve productivity in the United States through changes in indoor environments. They estimated that the potential annual benefits were:

- 10–30% reduction in acute respiratory infections, and reduced allergy and asthma symptoms
- 20–50% reduction in acute non-specific health symptoms
- 0.5–5% increase in the performance of office work
- associated annual cost savings and productivity gains of US$30–170 billion.

Bell et al. (2003) evaluated international literature and found 'a clear positive impact of the indoor environment on health and productivity of building occupants', but 'insufficient understanding . . . to determine the productivity or health benefits of a particular improvement in the indoor environment'.

9.6 BUILDING VENTILATION

Published data on ventilation rates in Australian buildings are limited but indicate ventilation rates became lower in **dwellings** during the 1990s and 2000s due to modified construction practices for energy conservation (improved gap sealing, absence of fixed vents). Similarly, ventilation rates in mechanically ventilated **office buildings** became low in the 1980s in response to ventilation codes of the time, but were increased by subsequent codes in the 1990s. The design, operation and maintenance of mechanical ventilation systems can all contribute to poor IAQ and **all** need to be addressed for IAQ control. Use of an alternative (improved) ventilation mode, such as displacement ventilation, is another approach for IAQ improvement. In displacement ventilation, 100 per cent outdoor air is introduced at floor level and rises by buoyancy to the ceiling where it is extracted and exhausted (that is, all air is exhausted and there is no recycling of the building air). Such a mode must be implemented from building design. However, its effectiveness may be impaired by disturbance of the vertical air movement due to occupants and their activities.

9.6.1 REGULATION

AS 1668.2 *Mechanical Ventilation for Acceptable Indoor Air Quality* (Standards Australia 1991) and AS/NZS 3666.1 *Air-Handling and Water Systems of Buildings—Microbial Control* (Standards Australia 2002b) are adopted through their reference in the Building Code of Australia (BCA) (ABCB 2005). The BCA has specific performance provisions for indoor air quality, but only in relation to ventilation with outdoor air, as follows:

> P.2.4.5 Ventilation
> (a) A space within a building used by occupants must be provided with means of ventilation with outdoor air which will maintain adequate air quality.
> (b) A mechanical air-handling system in a building must control—
>   (i) the circulation of objectionable odours; and
>   (ii) the accumulation of harmful contamination by micro-organisms, pathogens and toxins.
> (c) Contaminated air must be disposed of in a manner which does not unduly create a nuisance or hazard to people in the building or other property.

Note that the BCA does not define 'adequate air quality'. This performance can be met in any way, but options that are deemed to satisfy the BCA are:

- 'the use of a mechanical ventilation system in accordance with AS 1668.2' (Mechanical ventilation for acceptable indoor air quality); or
- 'by direct ventilation (or ventilation borrowed from an adjoining room) where there are specified areas of permanent openings, windows, doors or other devices'.

9.6.2 VENTILATION CHANGES OVER TIME

Generally, dwellings in Australia rely on natural air infiltration and operable windows for ventilation, while mechanical ventilation is the norm for large commercial buildings (without humidity control, since this is regarded as unnecessary in the largely temperate climate). Usually, AS 1668.2 (Standards Australia 1991; 2002a) has taken guidance from the code of the American Society of Heating and Refrigerating Airconditioning Engineers (ASHRAE), Standard 62 (ASHRAE 1973), and so the history of this code should be reflected in changes to AS 1668.2. This history is relevant since buildings were constructed to the Standard of the day and were not modified as the Standard changed.

The air-conditioning of buildings to provide occupant comfort became widely used for cinemas in the United States in the 1920s and gradually spread to other building types. Ventilation rates from the 1940s were influenced by the research of Yaglou and Witheridge (1937), who evaluated the outdoor air dilution–ventilation rates necessary for an occupied room such that 80 per cent of visitors to the room did not find body odours in the room objectionable. They determined that a minimum outdoor air ventilation rate of 5 litres per second per occupant was required. More recently, Fanger (1988) found a somewhat similar ventilation requirement using different methods, as presented in Figure 9.1. This shows that the percentage of occupants dissatisfied with indoor environments increases markedly for ventilation rates below 5 L/sec/person.

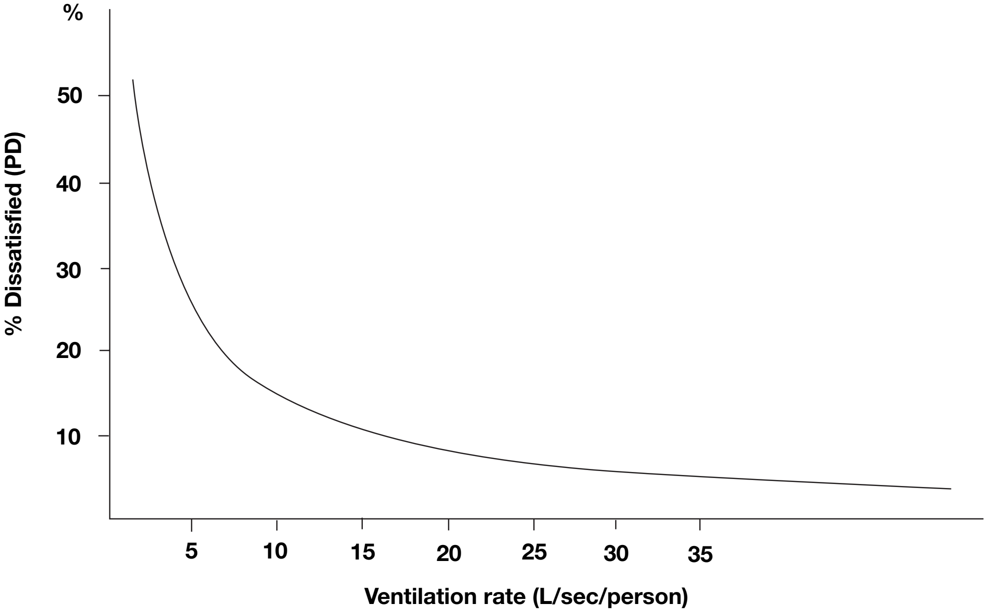

Figure 9.1 Perceived air quality (% dissatisfied) by a standard person at different ventilation rates
Source: CEC (1992)

ASHRAE Standard 62–1973 (ASHRAE 1973) specified minimum and recommended ventilation requirements for most buildings. These were believed to have worked well until the energy crisis in the late 1970s, when building operators lowered the amount of outdoor air brought into buildings. The revised ASHRAE Standard 62–1981 dealt with indoor air quality as well as odour issues, and this was revised again in 1989. In Australia, AS 1668.2 (Standards Australia 1991) reflected this last revision. ASHRAE Standard 62–1981 recommended outdoor air ventilation rates for smoking-permitted and smoking-prohibited conditions, but these proved to be confusing and were removed from Standard 62–1989, which recommended single rates allowing for 'reasonable' smoking levels. A comparison of the ventilation requirements for the different versions of ASHRAE Standard 62 (Meckler 1991) is shown in Table 9.4. Generally, this shows that minimum mechanical ventilation rate specifications for buildings designed during most of the 1980s were somewhat lower than those specified at other times.

Table 9.4 Ventilation requirements for various versions of ASHRAE Standard 62

Occupied space	Outdoor air ventilation requirement (L/sec/person except where indicated)				
	1973 version		1981 version		1989 version
	Minimum	Recommended	Non-smoking	Smoking	Ventilation
Dance venues	7.5	10–13	3.5	18	12.5
Bars	15	18–20	5.0	25	15
Beauty shops	12.5	15–18	10	18	12.5
Classrooms	5	5–8	2.5	13	7.5
Dining areas	5	8–10	3.5	18	10
Hospital patient rooms	5	8–10	3.5	18	12.5
Conference rooms	10–13	13–20	3.5	18	10
Offices	7.5	8–13	2.5	10	10
Residences	2.5	4–5	5	5	0.35 air changes/hour
Retail stores	3.5	5–8	2.5	13	1–1.5 L/sec/m^2
Smoking lounges	—	—	—	—	30
Spectator areas	10	13–15	3.5	18	7.5
Theatres	2.5	3–5	3.5	18	7.5

Source: Meckler (1991)

One of the major changes evident in ASHRAE Standard 62–1989 and AS 1668.2 (Standards Australia 1991) was the need to maintain a **minimum** outdoor air ventilation rate in **mechanically ventilated buildings**, which was increased from

2.5 L/sec/person in 1981 to 7.5 L/sec/person in 1991. The rationale for this increase was to maintain levels of indoor carbon dioxide exhaled by occupants to below 1000 ppm, this being used as a surrogate for unacceptable body odours to 20 per cent of visitors entering an occupied space, as shown in Figure 9.2. Odours from other sources are expected to require much greater ventilation rates, particularly in the case of tobacco smoke, which has been suggested to require an outdoor air ventilation rate of 50 L/sec/smoking person (Cain et al. 1983). Instead of using such high and unrealistic ventilation rates, it is preferable to follow the NOHSC (1994) recommendation that smoking should be restricted to 'designated smoking areas' separated from and with different ventilation systems from other occupied areas.

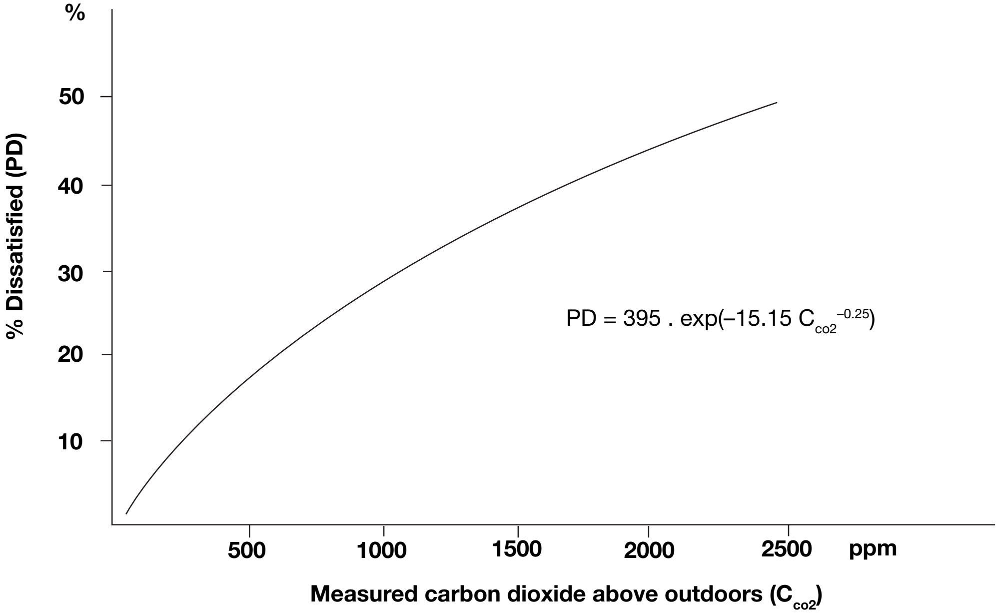

Figure 9.2 Perceived air quality (% dissatisfied) as a function of carbon dioxide concentration in buildings

Source: CEC (1992)

The ventilation standard AS 1668.2 *Ventilation Design for Indoor Air Contaminant Control (Excluding Requirements for the Health Aspects of Tobacco Smoke Exposure)* (Standards Australia 2002a) is structured somewhat differently from previous ventilation standards. It allows for either of two procedures to be used in ventilation design—a simple prescriptive procedure and a more complex engineered procedure. The former will be discussed briefly here and the reader should consult the Standard for a more thorough understanding. The prescriptive procedure introduces two factors, one for occupant-related contaminants and the other for building material and other non-occupant-related contaminants. The minimum flowrate of outdoor air supplied by the air-handling system in litres per second is determined for each contaminant. The required ventilation rate is the higher of the total for occupant-related contaminants or the total for building material/non-occupant-related contaminants.

The 2002 Standard set ventilation rates for enclosures in which smoking was *not* prohibited based on the 'amenity effects' (odour) of environmental tobacco smoke (tobacco smoke that accumulates and ages in indoor environments). The Standard did not address the health aspects of environmental tobacco smoke exposure. AS 1668.2–2002 has *not* been called up in BCA because of its lack of support by key organisations (Australian Building Codes Board, NOHSC, enHealth Council), largely on the basis of the need for health protection from environmental tobacco smoke.

While not systematically investigated, limited measurements have indicated that a large proportion of commercial buildings in Australia do not comply with AS 1668.2 (e.g. Williams 1992; Brown 1997), which is not surprising in view of the increases in the ventilation requirements of AS 1668.2 relative to previous requirements. In the absence of an ongoing requirement in regulations to check that the systems continue to perform to design specifications, **any IAQ investigation should first establish that the mechanical ventilation system does operate to current AS 1668.2 requirements prior to initiating any air sampling and IAQ assessment**. If a building is not provided with ventilation to the minimum requirements of the code, further investigation by air sampling must be considered of no real use in determining how to achieve acceptable air quality, at least until the required ventilation conditions are achieved.

9.6.3 PERFORMANCE AND MAINTENANCE OF VENTILATION SYSTEMS

A typical heating/ventilation/air-conditioning (HVAC) system is shown in Figure 9.3, and consists of extensive ductwork, air filters, fans (supply air, make-up air, room exhaust), cooling coils (with a well-drained condensate tray underneath to take away condensed water without pooling), heating coils, dampers, room air diffusers, return air grille, etcetera. Note that the one component that is not in contact with air supplied to the building is the cooling tower system, although it still may affect IAQ through the air it exhausts if contaminated with *Legionella* bacteria and able to find its way into buildings. Water cooling towers must be located well away from building air inlets and meet rigorous regulations for chemical treatment, monitoring, cleaning and (in some states) registration (see AS/NZS 3666.1 *Air-Handling and Water Systems of Buildings—Microbial Control*, Standards Australia 2002b). Refrigerative cooling systems do not have these requirements but, except for small units, are much more expensive to purchase and use more energy. Also, large refrigerative cooling systems can weigh substantially more than their equivalent water systems, preventing retrofitting of the former based on a building's load-bearing capacity.

In a typical HVAC system, a high proportion of room air (of the order of 80–90%) is usually recirculated by transport and treatment in the ventilation plant, with the remaining 10–20 per cent as 'make-up air' introduced from outside (i.e. the outdoor ventilation air referred to in the Standard). Quite aside from the required outdoor ventilation air, mechanical ventilation systems can lead to poor IAQ through poor operation and maintenance of the above components, especially where water and condensation factors are involved that can lead to growth of micro-organisms. **A written plan for periodic maintenance should be developed and followed, and maintenance activities should be documented.** Elements of periodic maintenance that are important for good IAQ include:

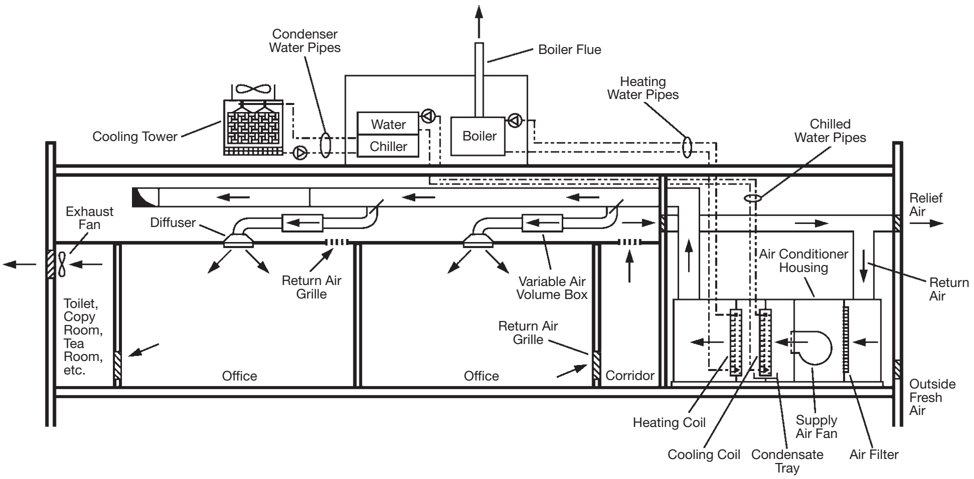

Figure 9.3 Schematic diagram of central mechanical ventilation/air-conditioning plant
Source: Comcare Australia (1995).

- changing of filters (besides blocking and restricting airflow, filters can become sources of odour and micro-organisms)
- checking correct installation of filters
- cleaning of condensate trays and cooling coils
- checking fan operation and operation of dampers that influence airflow rates.

Measurement and balancing of the ventilation rate from an HVAC system is a task for a specialist mechanical engineering consultant. The H&S practitioner can determine the need for this by measuring carbon dioxide levels in an occupied building as a surrogate for ventilation adequacy (see Section 9.2). In general, ventilation measurement may be necessary:

- after significant changes in the building, the HVAC system, or the occupancy and activity within the building
- when control settings have been readjusted by maintenance personnel
- when accurate records of the system's performance are not available.

Another practical aspect of ventilation systems is duct cleaning, although the need for and benefit from this practice is open to question. Dust build-up occurs within ducts (usually made from sheet metal and covered with insulation) because particulates in the air supply naturally deposit in small proportions to indoor surfaces. Until the deposition grows significantly enough to affect airflow rates (by reducing the cross-section of the duct) or to be dislodged by air turbulence, or unless moisture transport to the duct interior leads to growth of micro-organisms, there appears to be little benefit from duct cleaning in most commercial buildings. The common appearance of particles on ceiling surfaces adjacent to air inlet diffusers is likely to be just an extension of the dust deposition process beyond the ductwork. However, duct cleaning may be needed in mechanical ventilation systems for hospitals and food processors where more sterile surfaces are usually required.

AS/NZS 3666 *Air-Handling and Water Systems of Buildings—Microbial Control* (Standards Australia 2002b) is called up by the BCA. Also, each state may have legislation specifically directed to *Legionella* species control in cooling towers. AS/NZS 3666 prescribes a number of maintenance measures for HVAC systems including:

- annual inspection of ductwork in the vicinity of moisture-producing equipment, and cleaning where necessary
- annual inspection of coils, trays, sumps, condensate lines, duct terminal units, air intakes and exhaust outlets, and cleaning where necessary
- annual inspection of air filters, where installed, and cleaning or replacement where necessary
- monthly inspection of humidifier components, and cleaning where necessary
- monthly inspection of cooling towers, and cleaning where necessary—with 6-month maximum cleaning intervals unless otherwise approved.

9.7 RELATIONSHIP BETWEEN INDOOR AIR AND OUTDOOR AIR

Urban populations spend 96 per cent of each day, on average, in a range of enclosed environments such as the home (new, established, transportable), the workplace (non-industrial, industrial), school, shops, hospitality buildings and transit vehicles.

Figure 9.4 demonstrates the complexity of how pollutants arise and are distributed in a typical office building. Air pollutants are present within the office from four overarching factors, all linked to specific sources of the pollutants:

1. Outdoor air that is used to ventilate the office introduces outdoor air pollutants (carbon monoxide, VOCs such as benzene, particulates).
2. Virtually all manufactured products used to construct, furnish and operate the office act as emission sources for a diverse range of air pollutants (VOCs, formaldehyde, micro-organisms), some of which are also introduced with outdoor air.
3. The behaviour of occupants (e.g. smoking, use of appliances/equipment, pesticide use) introduces specific pollutants (particulates, ozone, carbon monoxide, pesticides, body odours/perfumes).
4. Pollutants that are present in indoor air are limited in their dispersion by the enclosed nature of building environments and will become present at higher concentrations if the ventilation rate is lowered.

It is important to realise that the ingress of outdoor pollutants will occur for all buildings, with the level of indoor air pollution depending on the level of outdoor pollution, the level and type of ventilation used, and the nature of pollutant losses to indoor surfaces (e.g. ozone decays rapidly on contact with indoor surfaces, while carbon monoxide does not deplete at all). Indoor air pollutants emitted from indoor materials and appliances will be present *in addition to* pollution resulting from outdoors, to an extent depending on the level of the product emissions, their persistence over time and the ventilation/indoor surface losses (Brown 1996; 1997; 1998; 1999a; 1999b; 1999c; 2000; 2002; Brown & Cheng 2003; Brown et al. 2004).

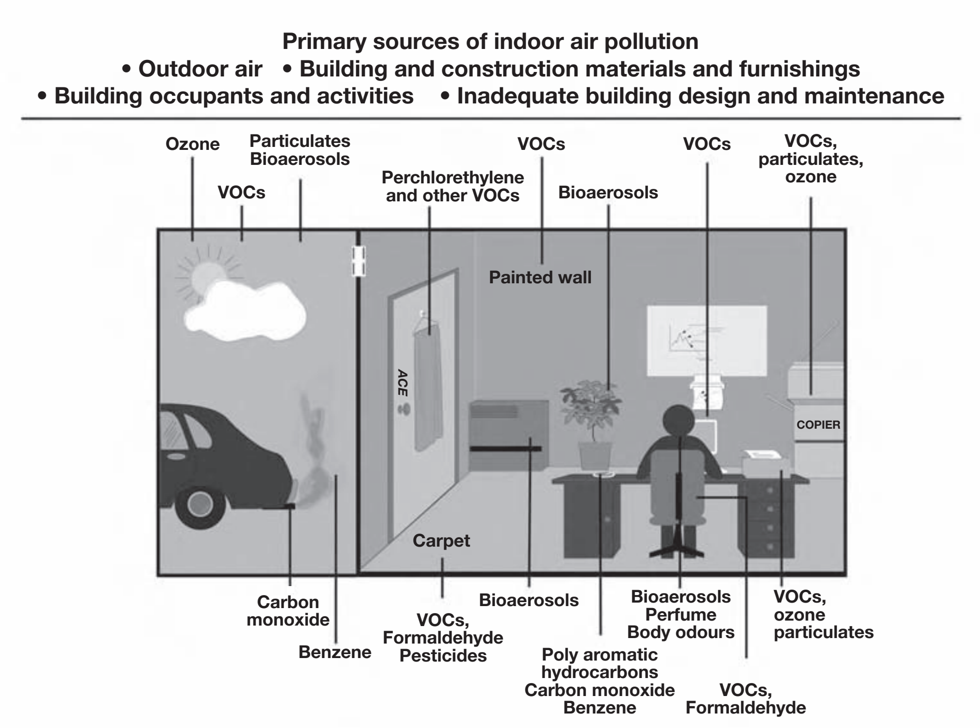

Figure 9.4 Primary sources of indoor air pollution
Source: Newton et al. (2001)

It is commonly found that indoor pollutant sources, where present, dominate in their impact on IAQ compared to outdoor air pollutants, as shown in Table 9.5. The important questions therefore relate to the number of highly polluting sources in buildings, and whether sectors of the population are exposed to the pollutants at levels considered to present risks to their health and wellbeing. Questions about the impact of outdoor air pollutants need to consider those urban environments where the greatest pollutant levels occur (e.g. near busy roads and city centres).

9.8 MAJOR INDOOR AIR POLLUTANTS AND SOURCES

The types of pollutants and the situations in which they occur in Australian buildings can be summarised as follows (Brown 1997):

Home

- Formaldehyde and VOCs from new building materials in new or renovated buildings (< 6 months old).

Table 9.5 Indoor and outdoor air pollutant levels for some Australian buildings

Pollutant	Indoor air goal (µg/m^3)	Typical indoor air concentrations (µg/m^3)			Typical outdoor air (µg/m^3)
		New house/office	Established house	Established office	
Formaldehyde	130 (NHMRC)	100–800	20–120	40–120	10–20
Total VOCs	500 (NHMRC)	5000–20 000	200–300	100–300	20–100
Nitrogen dioxide	225 (NEPM)				10–50 (300 peak)
• no unflued gas heater		–	10–35	–	
• unflued gas heater		–	60–1500	–	
Fine particles (PM$_{10}$)	50 (NEPM)				5–30
• smoking		–	>90	100–300	
• non-smoking		40–60	5–40	10–40	
Dust mite allergens (per gram of house dust)	2–10 µg/g (WHO)	<0.1	10–60 coastal <1 inland	<2 (data limited)	<0.1

Sources: Brown (1996; 1997; 1998; 2000; 2002); Mannins (2001)

- Formaldehyde in caravans/transportable buildings with high loading of reconstituted wood-based panels.
- House dust mite allergen exposure from carpets and bedding (except well inland and central Australia).
- Environmental tobacco smoke from occupants who smoke.
- Combustion products (nitrogen dioxide, carbon monoxide, formaldehyde) from unflued gas heaters and stoves.
- Auto-exhausts (benzene, 1,3-butadiene, respirable particles, carbon monoxide) if the dwelling has an attached garage.
- Asbestos from friable building materials when physically disturbed, especially insulation products (e.g. switchboard backing).

Offices/schools
- Formaldehyde and VOCs from new building materials in new or renovated buildings (<6 months old).
- Formaldehyde in transportable buildings with high loading of wood-based panels.
- Office equipment emissions (VOCs, ozone, respirable particles).
- Cleaning product residues.
- Auto-exhausts (benzene, 1,3-butadiene, respirable particles, carbon monoxide) from enclosed car park or if close to busy roads.
- *Legionella* bacteria associated with water cooling towers.
- Asbestos from friable building materials subject to damage (sprayed insulation for fire/acoustic/condensation control, boiler/pipe lagging, insulation board).

Shopping centres
- Miscellaneous emissions from consumables, cooking, etc.
- Auto-exhausts (benzene, 1,3-butadiene, respirable particles, carbon monoxide) from enclosed car park or if close to busy roads.
- *Legionella* bacteria associated with water cooling towers.
- Shared ventilation air from other tenancies that emit pollutants (e.g. print shops, hair and nail salons).

Hospitality buildings
- Environmental tobacco smoke from smokers.
- Auto-exhausts (benzene, 1,3-butadiene, respirable particles, carbon monoxide) from enclosed car park or if close to busy roads.
- *Legionella* bacteria associated with water cooling towers.
- Micro-organisms from persistently damp surfaces.

Transit vehicles
- Auto-exhausts (benzene, 1,3-butadiene, respirable particles, carbon monoxide) if in slow-moving traffic.
- VOCs in new vehicles up to ~12 months old.

The times spent in each of these environments will be important determinants of pollutant exposures (e.g. compare travelling to work in a new vehicle to working all day in a new vehicle) and can be estimated from ABS statistics for 1997 (Newton et al. 2001):

- Home — 57% of time.
- Employment + education — 14% of time.
- Shopping — 2% of time.
- Hospitality — 18% of time.
- Transport vehicles — 5% of time.
- Outdoors — 4% of time.

These figures show that people typically spend almost all of their daily time in enclosed environments (96%), and little time (4%) outdoors, which is consistent with findings in other developed countries.

The time spent in transport vehicles — 70 minutes per day on average — is of particular concern from the perspective of exposure to auto-exhausts (benzene, 1,3-butadiene, respirable particles, carbon monoxide) when in slow-moving traffic. Duffy and Nelson (1996) found that car occupants were exposed to much greater levels of these pollutants when travelling in urban traffic. A target level for this indicator needs to consider the pollutant levels experienced so that the population exposure distribution (pollutant level multiplied by time exposed) can be assessed and health risks can be estimated. For example, various studies have found that benzene concentrations within vehicles in urban traffic are 20–150 μg/m^3, which will impact the outdoor benzene exposure level recommended by the UK Health and Safety Executive of 3 μg/m^3 as an annual average. Also, occupants of new vehicles have been found to be exposed to elevated levels of VOCs from the cabin interior materials, these levels taking several months to deplete to levels below NHMRC's goal (Brown & Cheng 2003).

9.9 MICRO-ORGANISMS IN INDOOR AIR

There is significant concern in Europe and North America about micro-organisms as indoor air pollutants. These include viable and non-viable matter such as viruses, bacteria, fungi, protozoa, house dust mites and insect faeces and pollens. Their presence may result in infectious disease, toxic effects or allergic reaction. The occurrence and health effects of *Legionella* species and house dust mites are well understood in Australia, as discussed earlier, but there has been limited investigation of other micro-organisms. Generally, there has been little concern about the latter in Australia — this may be due to the temperate climate as compared to Europe and North America, where internal condensation may be more prevalent with severe winters. Overseas research has established associations between indoor dampness and ill health, but a critical evaluation of this research has concluded that there is little to no evidence to identify causative factors such as inhaled fungal spores from moulds in buildings (Lovic et al. 2005).

In any building, a variety of micro-organisms will be present at different times and within different locations. In order for airborne disease transmission to occur, there must be a source or reservoir for the micro-organisms, some means for them to multiply and a mechanism for their release and dispersion into indoor air (Burge & Feeley 1991). The major indoor reservoir is often stagnant water or moist interior surfaces. These can accumulate the micro-organisms that enter the building from outdoors, allowing them to multiply and to act as amplifiers. Airborne dispersion is relatively easy for micro-organisms found in ventilation systems or contaminated carpet. Hargreaves and Parappukkaran (1999) noted that exposure to moulds and fungi is an everyday occurrence for most people, but that the collective literature pointed to three key factors for elevated fungal populations:

- poor construction techniques
- failure to rapidly identify/repair water incursion
- failure to correctly operate and maintain air-conditioning systems.

Specific guidelines provided by the American Conference of Governmental Industrial Hygienists (ACGIH® 1989) relied primarily on site inspection for potential sources of micro-organisms. Air sampling was regarded as a secondary or last-resort action where occupant illness had occurred, and needed to be performed relative to outdoor air with determination of both taxa and concentrations.

Micro-organisms, particularly fungi, were considered to be associated with sick building syndrome symptoms in a mechanically-ventilated Sydney office building (Seneviratne et al. 1994). The building exhibited damp walls and 'high' fungi spore counts (primarily *Cladosporium*, *Aspergillus* and *Penicillium*; 600–2500 colony-forming units (CFU)/m^3). An Australian commercial microbiology laboratory (Stuttard 1996) is believed to routinely screen office buildings for airborne micro-organism levels using 'standardised' test methods (e.g. 20 or more sub-samples from each building; comparison to outdoor air levels), with a 'typical' range from 50 to 1500 CFU/m^3. It recommends an 'excellent' rating for buildings with:

- no more than one sample > 1000 CFU/m^3
- no more than five samples > 100 CFU/m^3
- no obvious Group 1 or 2 microbial pathogens noted.

Using a centrifugal air sampler (Biotest RCS, Japan) as a simple screening test (without speciation) for micro-organism contamination of buildings, Wakelam et al. (1995) and Brown (1998) investigated approximately 60 commercial buildings from 1991 to 1998. While neither study related the measurements to occupant illness, they found that fungi levels exceeding 200–500 CFU/m^3 and bacteria exceeding 500–1500 CFU/m^3 could be considered higher than normal and could complement visual inspection for moisture and growths on building interior surfaces.

Bacteria are also ubiquitous in air and the general environment, and can cause adverse human health effects and deterioration of building materials when they proliferate in indoor environments (Stetzenbach 1998). The health effects of bacterial exposure in indoor air will depend on the species and the route of exposure. The bacteria in building air can come from external sources—from wind disturbance of soil and vegetation, compost, municipal landfills, sewage sludge, etcetera. They can also be a direct result of human activity, such as breathing, coughing and sneezing, or they may colonise the ductwork of the cooling systems, the water cooling towers (e.g. *Legionella* species) or interior building materials and furnishings such as wallboard, wallpaper and flooring (Bates 2000). In indoor environments, bacteria usually grow in areas with standing water such as water spray and condensation areas of air-conditioning systems (Stetzenbach 1998). Indoor air consultants in Australia have found cases of standing water in non-draining condensate trays of air-conditioning systems. While the prevalence of this is unknown, building codes are now very specific about the requirement for self-draining condensate trays.

The Department of Health and Ageing (DHA 2004a; 2004b) has concluded:

- Fungi, bacteria and allergens from house dust mites, cats and cockroaches are important indoor biological pollutants.
- Asthma triggers are manifold but include allergens—these are usually small glycoproteins which provoke an immune response in allergic people, and include house dust mites, animal skin and saliva, pollen, moulds and, in rare cases, foods.

Similar to other environmental allergens, indoor exposure to mould has been shown to correlate with wheezing and peak flow variability. Fungal exposure occurs both indoors and outdoors. Exposure to moulds such as *Alternaria* increases the risk of asthma symptoms and airway reactivity in sensitised children and the risk of sudden respiratory arrest in sensitised young adults with asthma.

Many studies have shown that sensitisation to environmental allergens is strongly associated with childhood asthma. However, the potential benefit of allergen avoidance in prevention of asthma is unproven.

To prevent development of asthma, house dust mite avoidance measures in infants may be considered. However, it is unlikely this will influence wheezing or childhood asthma beyond the first year of life. Apart from avoidance of cigarette smoke, no recommendations can be made regarding other exposures.

9.10 DYNAMICS OF INDOOR AIR POLLUTANTS

Indoor pollutant concentrations will vary substantially:

- from location to location, e.g. dust mite allergen and micro-organisms will be higher in tropical Queensland than cold–temperate SE Australia
- from building to building, depending on building age and type, the materials used, occupancy level and type, and the ventilation system
- within a building over a day as occupancy levels and occupant activities fluctuate, for example carbon dioxide levels will start to increase in the morning as occupants arrive and may not reach steady-state levels (as a measure of ventilation air delivery) until the afternoon
- within a building over the initial 6–12 months from construction when pollutants such as formaldehyde and VOCs will be highest since they are emitted from new building materials, appliances and furniture
- within a building according to the proximity to significant sources of pollutants, for example exhausts from copiers and printers.

The most significant factors influencing the indoor pollutant concentrations will be:

- the pollutant sources and their emission–time profiles
- design, maintenance and operation of the building ventilation system, as well as other processes for pollutant removal (e.g. local air extraction, cleaning practices)
- moisture control in the building to prevent condensation.

A detailed discussion of the variation in indoor air pollution over time and building location is beyond the scope of this chapter, but information can be found in the references and further reading presented in sections 9.13 and 9.14. The important considerations for the H&S practitioner are that IAQ is a dynamic variable, and that this has significance for its measurement and control.

9.11 MEASUREMENT OF IAQ

9.11.1 SAMPLING PROTOCOLS

Sampling protocols for indoor air have received little attention in published literature and are rather variable, since indoor air sampling is carried out for varied reasons (e.g. epidemiological studies, compliance with exposure guidelines, resolution of occupant complaints, baseline monitoring, and identification of pollutant sources). A critical aspect of a sampling protocol is the duration over which the air sample is taken. This must be matched to the anticipated biological effect of the pollutant. Short-term (tens of minutes) samples are needed for assessment of irritants, asphyxiants, sensitisers and allergenic agents. Long-term exposure duration is expected to be irrelevant for strong tissue irritants with immediate effect. For chronic disease agents, long-term samples (over several hours to days) are most relevant. Seifert (1984) noted that the period and location of sampling must depend on whether the pollutant source is long term (e.g. formaldehyde from particleboard) or short term (e.g. use of spray products). For the former, he recommended sampling under building conditions that allowed the estimation of average pollutant levels (e.g. 2–3 hours after closing windows), as well as low (far away from source) and high (after closing up room with source) pollutant levels. Corn (1985) described air sampling strategies for workplaces which are analogous to indoor air sampling in any building. He recommended that the strategy must allow estimation of the full range of pollutant concentrations, but that highest concentrations should be targeted if resources are limited. Ideally an average concentration and the degree of variability are determined. For workplaces he recommended a minimum of three samples per building with selection of sampling sites by a 'zoning method' where employees were grouped on the basis of job and environmental similarity. This was considered more efficient in determining high-exposure locations than strict random sampling. A similar strategy has been recommended for indoor air sampling (Thorsen & Molhave 1987; Ryan & Lambert 1992).

An authoritative review of sampling strategies was presented by the Commission of European Communities (CEC 1989). Minimum sampling strategies were recommended for pollutants, as summarised in Table 9.6.

In summary, sampling protocols for IAQ measurements should consider:

- building sample selection—'zoned' according to known sources of indoor air pollutants in order to focus on high exposure locations
- building operation—in a manner which maximises pollution during the period of pollutant sampling
- sampling period—to occur over a time scale relevant to the anticipated biological effect of the pollutant
- number of buildings—sufficient for a reliable estimate of exposure for 'at-risk' populations.

9.11.2 MEASUREMENT METHODS

Australian Standards® exist only for a limited number of indoor air pollutants, either because the methods have yet to be standardised or because those methods currently standardised were developed for industrial environments and lack sufficient sensitivity to measure indoor air pollutants. This section will present Australian and other countries' standard methods for measurement of indoor air pollutants. The H&S practitioner should also refer to Chapter 5, Aerosols, and Chapter 7, Gases and Vapours, for guidance on specific instruments to use in air sampling.

9.11.2.1 Formaldehyde

Formaldehyde is measured using AS 2365.6 *Determination of Formaldehyde-Impinger Sampling in Chromotropic Acid Method* (Standards Australia 1995b), in which fritted glass bubblers (two in series) containing a sodium hydrogen sulphite solution (approximately 15 ml) capture the formaldehyde from room air, generally as 30–60 L samples of air collected over a 30–60-minute period. The sample is subsequently analysed by UV-spectroscopy. An alternative procedure is to sample with dinitrophenyl hydrazine reagent and analyse using liquid chromatography.

9.11.2.2 Volatile organic compounds (VOCs)

VOCs in industrial workplaces are usually measured in accordance with AS 2986.1 *Workplace Air Quality—Sampling and Analysis of Volatile Organic Compounds by Solvent Desorption/Gas Chromatography* (Standards Australia 2003a), equivalent to ISO Standard 16200 (ISO 2003) in which air is sampled onto activated charcoal or other sorbents and subsequently solvent-desorbed for GC analysis. The method has inadequate sensitivity (1–10 mg/m^3 per VOC) for indoor air. Generally, methods in which thermal desorption or cryo-focusing are used have 100-fold more sensitivity than solvent desorption, and are the preferred methods for IAQ. For VOCs with boiling points above 60°C (WHO 1982), these two basic approaches are each specified in USEPA (1997; 1999a) and ASTM (2001; 2003) standards.

The measurement of ppb levels of VOCs using a sensitive photo-ionisation detector has been suggested by manufacturers as an alternative to the above methods. However, the instrument does not identify the VOCs present, lacks high sensitivity, has cross-sensitivity to other gases, and responds differently to different VOC mixtures.

Table 9.6 Sampling protocols for private and public buildings recommended by CEC (1989)

Pollutant	Building parameter	Objective of measurement	
		Average concentration	Maximum concentration
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Temperature/RH	Normal conditions for all	Normal conditions (except formaldehyde 25°C and 60% RH)
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Ventilation status before sampling	Normal conditions for all	Natural vent.—close door and windows 1–5 hours before sampling Mech. vent.—minimum likely rate
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Ventilation status during sampling	Normal conditions for all	Natural vent.—close door and windows Mech. vent.—minimum likely rate (additional fan stirring for asbestos)
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Occupancy	Normal conditions for all	Normal to maximum, with dry dusting to cause resuspension of particles
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Source status	With and without pollutant-producing activities if testing for sources	Heavy use of source and maximum occupant activity as appropriate
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Sampling location	Centre of room 1–2 m high (ground floor for radon), outdoor ~5 m away	~1 m from suspected source 1.5–2 m high; in basement/lowest level for radon
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Time to sample	Summer and winter, usually during working hours	Any time that sources/activities/ventilation may cause maximum
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Sampling period	1 day or more 1–7 days 8 hours 5–14 days	30–60 minutes (direct reading) >1 day 4 hours 30–60 minutes
Formaldehyde, NO_2, RSP, radon, asbestos, VOC	Minimum number of samples	For orientation—1 For control or compliance—2 to 3 (for asbestos, also settling samples over 1–2 weeks)	For orientation—1 For control or compliance—2 to 3 (for asbestos, also settling samples overnight)

9.11.2.3 Pesticides

There are no relevant Australian Standards® for pesticide measurement in air. Workcover NSW uses sorbent sampling with a detection limit of 40 μg/m^3, which may not be sufficiently sensitive for many situations. A method published by the USEPA (1999b) has detection limits from 0.001 to 50 μg/m^3 for 4- to 24-hour sampling periods.

9.11.2.4 Carbon monoxide

AS 2365.2 *Methods for the Sampling and Analysis of Indoor Air—Determination of Carbon Monoxide—Direct-Reading Portable Instrument Method* describes a method for measuring concentrations of 0–500 ppm (Standards Australia 1993).

9.11.2.5 Carbon dioxide

There is no relevant Australian Standard® though carbon dioxide is commonly measured using instruments with gas infrared detectors at concentrations from ambient (350 ppm) to 5000 ppm.

9.11.2.6 Nitrogen dioxide

AS 2365.1.2 *Methods for the Sampling and Analysis of Indoor Air—Determination of Nitrogen Dioxide—Spectrophotometric Method—Treated Filter/Passive Badge Sampling Procedures* (Standards Australia 1990a) has a detection limit of 0.035 ppm for a 2-hour sampling period and can measure down to the NEPM level of 0.12 ppm over 1 hour. Active air sampling into an impinger containing the same reagent can be used for higher sensitivity.

9.11.2.7 Ozone

For ambient air, ozone is commonly measured using a direct-reading UV absorption instrument according to AS 3580.6.1–1990 *Methods for Sampling and Analysis of Ambient Air—Determination of Ozone—Direct-Reading Instrumental Method* with a measurement range to 0.5 ppm and detection limit below 0.01 ppm (Standards Australia 1990b). Such instruments are expected to be too large and expensive for typical indoor air assessments. Portable instruments based on electrochemical cells may be used as alternative (non-standardised) methods of measurement, but may underestimate levels due to the high surface reactivity of ozone.

9.11.2.8 Radon

AS 2365.4 *Methods for the Sampling and Analysis of Indoor Air—Determination of Radon* specifies three methods for radon measurement with detection limits of 3–40 Bq/m^3 (Standards Australia 1995a).

9.11.2.9 Respirable particulate matter

The NHMRC (1996) goal for respirable particulate matter (RPM), shown in Table 9.2, has been superseded by the NEPM (Table 9.3) based on PM_{10} (goal 50 μg/m^3 over a 1-day period) and $PM_{2.5}$ (advisory reporting standard: 25 μg/m^3 over a 1-day period; 8 μg/m^3 over a 1-year period). These measures, AS/NZS 3580.9.6 *Methods for Sampling and Analysis of Ambient Air—Determination of Suspended Particulate Matter—*PM_{10} *High Volume Sampler with Size-Selective Inlet—Gravimetric Method* (Standards Australia 2003b) and

AS/NZS 3580.9.10 *Methods for Sampling and Analysis of Ambient Air—Determination of Suspended Particulate Matter—$PM_{2.5}$ High Volume Sampler with Size-Selective Inlet—Gravimetric Method* (Standards Australia 2006) are based on a size selection for particles with a 50 per cent cut point at 10 µm and 2.5 µm equivalent aerodynamic diameters (EAD) respectively. Historically, workplace atmospheres have been evaluated for exposures to respirable dust, as in AS 2985 *Workplace Atmospheres—Method for Sampling and Gravimetric Determination of Respirable Dust* (Standards Australia 2004). This describes a method for determination of respirable dust which, when inhaled, penetrates to the unciliated airways, or alternatively it can be described by a cumulative log-normal distribution with a median EAD of 4.25 µm and a geometric standard deviation of 1.5. The practical detection limit for sampling periods greater than 60 minutes is greater than 10–100 µg/m^3 depending on microbalance sensitivity. This sensitivity is acceptable for evaluating occupational exposure standards in the mg/m^3 range, but is problematic for evaluating exposures compared with the NEPM goals unless long sample times are used.

In recent years, direct-reading, portable laser light-scattering (LLS) instruments have been used for measuring respirable particulate matter. Generally, they have high sensitivity and allow changes over the work day to be evaluated. However, they are usually calibrated with particle standards that may differ in response from real-world particles. For example, Kim et al. (2004) found good agreement between LLS and gravimetric measurement of $PM_{2.5}$ for boilermakers exposed to welding fumes and ash, while Chung et al. (2001) found an LLS instrument consistently overestimated urban air $PM_{2.5}$ by a factor of 3 relative to gravimetric measurement. Heal et al. (2000) used an LLS instrument to monitor undisturbed indoor air and found it overestimated PM_{10} by a factor of 2.0 and $PM_{2.5}$ by 2.2 relative to gravimetric measurement.

9.11.2.10 Environmental tobacco smoke

In the past, environmental tobacco smoke (ETS) was measured by surrogate measures such as concentrations of respirable particulate matter or nicotine, but such measures appear to be suited only to high levels of ETS. Guerin et al. (1992) developed a procedure to measure combustion-derived particulates as UV particulate matter (UVPM) or fluorescent particulate matter (FPM), which are expected to be more robust and sensitive surrogates for ETS, provided that other combustion sources are not present. These procedures have been standardised (ASTM 2002). The test methods are based on the collection of total RSP on a membrane filter, extracting the collected material in methanol, and measuring total UV absorbence or fluorescence, or both, of this extract. Studies have shown that UVPM/FPM concentrations occur at up to 50–100 µg/m^3 in areas with heavy smoking, but at <2 g/m^3 in the absence of smoking (Connor et al. 1990; Sterling et al. 1996). Measurement accuracy (3-hour sample period) is adequate at medium ETS levels (standard deviation of about 5% at 20 µg/m^3), but becomes poorer at low levels (less than about 5 µg/m^3) due to the confounding effects of combustion-derived particulates from outdoor air.

9.11.2.11 House dust mite allergen

The indicator for house dust mite (HDM) exposure (CEC 1993) should be the allergen levels in accumulated dust. This dust is collected by standard methods from mattresses, carpets and furniture, and analysed by an immunochemical assay, preferably enzyme-linked immunosorbent assay for the main house dust mite allergen of concern, Der p1. The indicator can be evaluated against hygienic threshold limits (HTL) proposed by Platts-Mills and de Weck (1988) or categories (based on measured values in residences) recommended by CEC (1993). These limits and categories (all based on allergen levels in collected dusts as Der p1 levels [μg/g dust]) are:

- CEC very low <0.5
- HTL for sensitisation 2
- CEC low <5
- HTL for acute attacks of asthma 10
- CEC intermediate <15
- CEC high <20
- CEC very high >20.

9.12 CONTROL OF IAQ

Ideally, IAQ control is applied at the **design stage** of buildings by:

- the selection of low-emission building materials, appliances and furniture
- ensuring ventilation to BCA requirements or better (e.g. use of newer methods of mechanical ventilation where feasible, such as displacement ventilation, hybrid ventilation—see Brown 1997; Spengler et al. 2001)
- ensuring persistent condensation and water pooling is prevented at *all* interior surfaces and locations, especially in HVAC systems (the condensate tray is a key location where water can stagnate and emit fungal and bacterial spores into building air and so it must freely drain)
- having a plan for operation and maintenance requirements of building services
- documenting all the above actions for future review and assessment where needed.

More likely, the H&S practitioner will become involved in IAQ complaints in existing buildings where the cause of complaints is unknown, poor details on the building are available and the ability to exert control is limited. For such situations, the approach of the *State of Environment Report on Indoor Air Quality* (Brown 1997) is recommended, which is a stepwise assessment approach designed to target IAQ problems in the following logical sequence:

Step 1: Inspect the building to ensure that it functions as originally designed and to accepted general practice (e.g. use a checklist of building faults, building contents, cleaning practices).

Step 2: Inspect operational components of the building for proper function (e.g. ventilation/heating/cooling appliances).

Step 3: Apply a 'standard' indoor air environment questionnaire to occupants to determine personal wellbeing and environmental comfort. A starting point for such a questionnaire is the Building Research Establishment/Royal Society of Health office environment survey (Raw 1995).

Step 4: Take air samples for assessment relative to NHMRC or other indoor air quality goals where potential sources of pollutants are identifiable from building inspection (e.g. carbon monoxide and nitrogen dioxide should only be sampled where indoor combustion processes (heating, cooking, car parking) are active; radon should only be sampled in a habitable cellar). The logistics of sampling (where, when, how and for how long) must be planned to simulate the worst-case scenarios relative to known sources (e.g. sampling of nitrogen dioxide when an unflued gas heater is operating and all external doors and windows are closed), or be based on sufficient repeat samples to estimate the full range of concentrations. Standard sampling and analysis procedures should be used where available (Australian or other).

Step 5: Record results of sampling and analysis for comparison with IAQ goals, with baseline results of similar buildings, and with future assessment of IAQ in the building.

At all steps: Identify factors where action is necessary, take such action as appropriate and determine impact on IAQ complaints, before moving to the next step.

Generally, it is recommended that an H&S practitioner who needs to investigate suspected IAQ problems should consult an occupational hygienist who has IAQ experience and expertise.

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10. Noise and vibration

Beno Groothoff MAIOH

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10.1 INTRODUCTION

Noise is one of the most pervasive health hazards the H&S practitioner has to deal with. Industry is noisy, offices and places of entertainment can be noisy, traffic and transport vehicles of all kinds can be noisy; few workplaces escape completely the intrusion of distracting noise or noise which is a hazard to hearing and health. Mechanisation and modern lifestyles have not alleviated the problem; in fact the opposite has occurred, with widespread and sustained noise exposures occurring in an increasingly noisy world.

Occupational exposure to noise, its physiological and psychological consequences, and methods of control are all very large areas of study. Noise-induced hearing loss constitutes one of the largest single causes of occupationally-related disabilities, and is a major occupational disease which accounts for a large percentage of workers' compensation claims. The *National Standard for Occupational Noise* (NOHSC 2000) states in its preface that noise-induced hearing loss imposes a severe burden on health and social services and the Australian economy as a whole.

The effect on workers from vibration is gaining more attention as the effects of vibrating plant and equipment are better understood. Legal precedents have also been set, with rather large compensation payouts in the United Kingdom for sufferers of vibration white finger or hand-arm vibration syndrome (HAVS) due to their long-term exposure to hand and arm vibration. Similarly, the effects of whole body vibration on drivers of vehicles such as trucks and earthmovers are being studied more extensively to avoid or minimise health effects.

In this chapter the recognition, evaluation and control of noise and vibration are only examined in general terms. The H&S practitioner is referred to some of the bibliographic references for more detailed treatments.

The phenomena of acoustic shock and ototoxicity are also introduced. Acoustic shock is a relatively new concern for workers in the call centre industry, which can have severe consequences for these workers if no protective measures have been taken by the call centre operators.

The effects of certain industrial chemicals on hearing are becoming better understood also. Because many workers are exposed to both noise and chemicals at work there is a growing awareness that the effects of chemicals which are known to be ototoxic should be considered in hearing conservation programs.

10.2 REGULATORY NOISE LIMITS

The *National Standard for Occupational Noise* (NOHSC 2000), adopted by health and safety authorities in Australia, limits a worker's noise exposure to $L_{Aeq,8h}$, 85 dB(A) referenced to 20 µPa (i.e. an average of 85 dB(A) over an 8-hour exposure), or a C-weighted peak sound pressure level of 140 dB(C), referenced to 20 Pa.

This does not mean that for all occupations such noise levels should be tolerated. For example, people in an open plan office or call centre could not work effectively with the distraction presented by noise levels of 85 dB(A) or even 75 dB(A). Effective communication and mental concentration are impaired by high levels of noise and may affect health and other aspects of safe work. Modern OH&S legislation requires that obligation holders conduct risk assessments to prevent or minimise risk. This applies equally to low level and high level noise, both of which cause communication and other problems that can impact on health.

10.3 PHYSICAL CHARACTERISTICS OF SOUND AND NOISE

Sound originates from a vibrating source causing variations in the atmospheric pressure which are detected by the ear and interpreted by the brain. Sound may convey useful information. When sound is unintelligible, unwanted, or may cause damage to hearing, it is referred to as 'noise'. A person gains all the information about, and identifies the uniqueness of, a sound by virtue of only three features: **combinations of frequencies**; their **relative intensities**; and the rate of **onset and decay** of the combinations of sounds of different frequencies. Any differences in sounds (e.g. a bird call, a violin or a chainsaw) are all attributable to the combination of these three features.

As sound is transmitted through the elastic medium of air, the air is compressed and rarefied to form a pressure wave like the ripples on a pond when a pebble is thrown in the water. The number of pressure variations per second is called the frequency of sound and is measured in Hertz (Hz) (see Figure 10.1). The wavelength is the distance between two similar points on the sine wave. The velocity of sound (wavelength × frequency), depends on the mass and elasticity of the conducting medium. In air, sound propagates at about 344 m/s at 20°C. In water, sound propagates at about 1500 m/s, and through steel it propagates at about 6000 m/s. The spectrum of good human hearing ranges between about 20 and 20 000 Hz, and everyday sounds contain a wide mixture of frequencies. Speech communications rely on frequencies ranging between 100 and 5000 Hz. Audible sound pressure variations are superimposed on the atmospheric air pressure (100 000 Pa) and normally range between 20 μPa and 100 Pa.

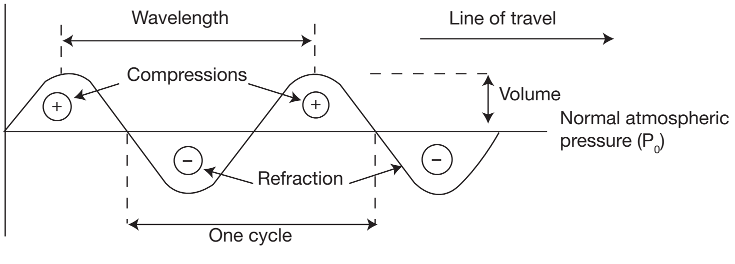

Figure 10.1 Sound as represented by an advancing pressure wave in air
Courtesy B. Groothoff

10.4 SOUND PRESSURE, DECIBELS, LOUDNESS AND THE $L_{EQ,60S}$

The quietest sound that can be detected by a young person with healthy ears is 20 millionths of a Pascal (20 µPa) at 1000 Hz. This has been standardised as the threshold of hearing (0 dB) for the purpose of sound level measurements and is used as reference level (P_0). A sound pressure of 100 Pa (130 dB) is so loud it causes pain in the average person and is therefore called the threshold of pain.

Sound pressure variations of a pure tone fluctuate so that for half the time of a complete cycle they are above (+) and the other half they are below (–) atmospheric pressure. The average pressure fluctuation therefore is zero due to equal positive and negative changes. To overcome this, the average pressure is squared over a large number of cycles and the square root taken. The resulting value, the root mean square (rms), is used in sound level measurements, as it is proportional to the energy content. For pure tones the rms is equal to 0.707 times the amplitude (volume) of the sine wave.

In terms of sound pressure detected by the ear, the loudest sounds heard at the threshold of pain are up to 10 million times greater than the softest. If calculations were to be made using a linear scale this would lead to using large and unwieldy numbers. Additionally, the human ear does not respond linearly but logarithmically to sound stimulus, so it is therefore more practicable to express acoustic parameters as a logarithmic ratio of the measured value to the reference value. This produces a more manageable relationship in comparisons of sound pressures and the resulting unit, the Bel (after Alexander Graham Bell 1874–1922), is defined as the logarithm to the base 10 of the ratio between two acoustical powers or intensities. This unit is still large, so the **decibel** (one-tenth of a Bel) is generally used. The decibel is defined as:

$$L_p = 20 \log p/p_0 \text{ [dB]} \qquad \text{(Equation 10.1)}$$

where:

L_p = root mean square (rms) sound pressure level, re 20 µPa
p = the rms sound pressure in Pascal, and
p_0 = reference sound pressure (20 µPa)

For a doubling of sound energy, the logarithmic scale increases by 3 dB, and a 100-fold increase in noise results in a 20 dB increase in scale.

Some examples of indicative noise levels in decibels are shown in Table 10.1.

Sound pressure levels represent only part of the picture. The apparent loudness of a sound depends very much on frequency, since the ear detects sound intensity with different sensitivities depending on the frequency composition of the sound. The ear is most sensitive to frequencies between 1000 and 4000 Hz, with sensitivity falling off at low and very high frequencies. Therefore high frequency sounds are heard much better than low frequency ones of equal intensity. Further, an individual's loudness interpretation and experience are subjective, depending on the harshness or intrusiveness of a noise (e.g. bagpipes compared with a flute), which are factors not reflected by the sound level measuring instrument.

Table 10.1 Indicative noise levels of various sources

Sound	Sound pressure level dB re: (20 μPa)
Firearm	155–165
Jet engines	140–150
Threshold of pain	130
Jackhammer	110
Nightclub	100
Noisy factory	90–95
Passing heavy traffic	80–90
Office environment	45–70
Speech	60–65
Inside a home	40
Whisper	20
Threshold of hearing	0

To match measured sound levels to those that correspond to the response of the human ear, measuring instruments are fitted with sound level weighting filters. The internationally adopted A-weighting is most commonly used, as it best corresponds to the response of the human ear. Sound pressure levels measured with the A-weighting filter are denoted as dB(A). This A-weighting response is illustrated in Figure 10.2, which shows clearly how the low frequency response is weighted downwards—that is, a sound level meter using the A-weighting reads lower than the actual (linear) response at frequencies below 1000 Hz.

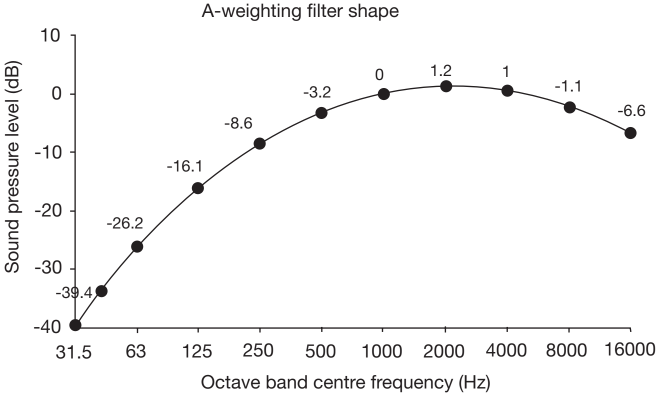

Figure 10.2 Frequency response attenuation characteristics for the A-weighted network

The A-weighted scale has been generally adopted as it attenuates broadband frequencies in a way that reflects their association with noise-induced hearing loss. It is the higher frequencies, thought to be above 1000 Hz, which give rise to most hearing damage. The 8-hour noise exposure limits of the national standard are based on A-weighted measurements (NOHSC 2000).

Few workplaces have the constant noise levels of, for example, dust extraction cyclones or electrical generators. Noise tends to be intermittent, like clanking machinery, passing traffic, or mechanical percussion of hammers, chippers or grinders. Thus noise levels may vary quite widely. OH&S legislation accommodates this by requiring the average A-weighted noise level over an 8-hour work period ($L_{Aeq,8h}$) to be determined and compared to the legislated exposure limit. To obtain an 'average' value of the noise, an integrated value called the equivalent continuous sound (energy) level over a measurement period T, of say, 60 seconds ($L_{Aeq,60}$), provides a measure of the acoustic energy of the fluctuating noise during the measurement period. The $L_{Aeq,60}$ is one parameter that finds convenient use in occupational noise exposure level surveys.

10.5 EFFECTS ON HEARING

The principal health-related effect of noise exposure is hearing loss. Excessive noise can destroy the ear's ability to hear, and the damage is not reversible. Hence, the H&S practitioner should put great emphasis on prevention. Damage to hearing depends on how loud the noise is and the length of the exposure. Other parts of the body (Figure 10.3) may also be affected by noise.

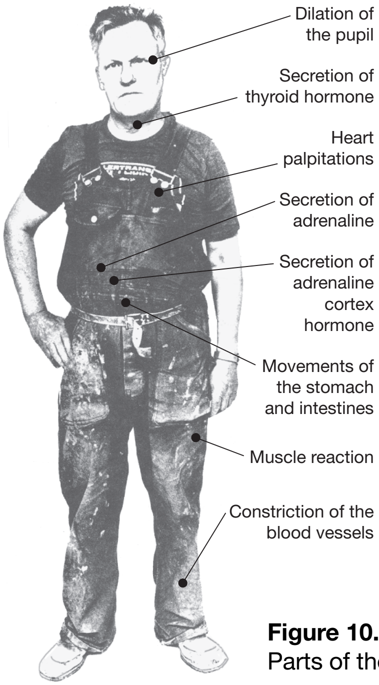

Figure 10.3
Parts of the body affected by noise

Noise also impairs communication, making it harder to do a job, and in the social sphere it spoils much of our enjoyment of life. Hearing normally deteriorates with age (presbycusis), and permanent hearing loss induced by noise can accelerate presbycusis and drastically affect quality of life.

- **Temporary threshold shift** in hearing occurs during or immediately after exposure to significant loud sounds. Quiet sounds can no longer be heard, and the condition may last for minutes to hours and days. This is caused by the hair cells in the hearing organ (cochlea) becoming reversibly desensitised.
- **Permanent threshold shift** results from long-term regular exposure to loud noise, particularly higher pitched noises. Noise-induced hearing loss (NIHL) is not reversible as it arises from the destruction of the hair cells in the cochlea. The left-hand photograph of Figure 10.4 shows healthy hair cells—a single row of inner hair cells and three rows of outer hair cells. The right-hand photograph shows a large number of destroyed hair cells. The human ear does not have the ability to regrow hair cells and there is no medical treatment.

Figure 10.4 Destruction of hair cells as a result of noise-induced hearing loss
Source: US Dept of Labor

- **Tinnitus** or 'ringing in the ears' sometimes accompanies NIHL. It may manifest as ringing, clicking, cicadas or continuous tones, and can be extremely distracting and even tormenting. Tinnitus can also happen after exposure to loud noise which causes a temporary threshold shift, for example using a jackhammer without wearing hearing protectors, or after a rock concert.
- **Acoustic trauma** normally results from high intensity explosive- or loud impact-type impulsive noise, which can destroy the hair cells and other ear mechanisms after one or relatively few exposures.

10.6 ASSESSMENT OF NOISE IN THE WORKPLACE

Two practical approaches can be employed by the H&S practitioner in assessing noise in the workplace. Both, however, require sophisticated equipment and reasonable levels of competency for proper measurement and interpretation. Acoustic consultants should be sought to advise the H&S practitioner where either equipment or competency cannot be secured.

10.6.1 THE SOUND LEVEL METER

AS/NZS 1269.1 *Occupational noise management—Part 1: Measurement and Assessment of Noise Immission and Exposure,* states that an integrating sound level meter of at least Class 2 should be used (Standards Australia 2005b). A Class 1 integrating sound level meter is the preferred instrument for measuring sound pressure levels. Such instruments, similar to that shown in Figure 10.5, provide simultaneous noise measurements in a range of different parameters, such as rms sound level $L_{Aeq,T}$, peak sound levels (L_{Cpeak}), A- and C-weighting and linear (flat response) dB measurements.

Figure 10.5
Sound level meter monitoring noise levels of angle grinder operator
Courtesy B. Groothoff

In Figure 10.2 the A-weighting response curve (matching the ear's sensitivity) of the sound level meter was shown. This curve follows different values at different frequencies from the horizontal 0 dB line. These values are used in noise control where the results of octave band analysis have to be expressed in an A-weighted value. Another weighting often used in controlling noise is the C-weighting. This weighting follows a different curve which is essentially horizontal (flat) between 80 and 3150 Hz and only tapers off outside this frequency range. The C-weighting is predominantly used with measuring peak sound pressure levels and determining the suitability of hearing protectors in a particular work environment.

Modern sound level meters can, depending on the software installed, also provide 'octave', or 'one third octave' (frequency) analysis at the same time as other parameters are measured. This enables measurements to be made of the sound spectrum in a range of frequencies determined by the meter's capabilities. Frequency analysis is necessary for the proper analysis of noise in the design of noise control measures, or provision of appropriate hearing protective devices in a particular work environment. The use of frequency analysis is examined further under noise control strategies (Section 10.9).

The sound level meter is used principally for determining the noise levels present at fixed work locations, for measuring noise levels of machinery, equipment, processes or work activities.

There are a number of cheap and simple-to-operate sound level meters available that may be useful to the H&S practitioner who is inexperienced in conducting sound level measurements. These meters do *not* meet the AS/NZS 1269 requirements and should never be used to demonstrate compliance with OH&S legislation. They may, however, be useful for indicative purposes, as would typically be the case with 'walk through' audits to determine whether or not the workplace is likely to contain excessive noise. Where this is the case more competent assistance should then be employed to conduct detailed noise surveys and identify control options.

10.6.2 PERSONAL NOISE DOSE METERS

Many workers move in their jobs from one noisy environment to another. Their total noise exposure therefore is the sum of the many different partial exposures. The personal noise dose meter (also known as dosimeter) (Figure 10.6) provides an integrated noise exposure over a known period, usually the work shift. Modern noise dose meters provide data logging with computer readable output, in dose, $L_{Aeq,8h}$, and A-weighted noise exposure, $E_{A,T}$, expressed in Pascal squared hours (Pa^2h), C-weighted peak readings, warning when daily exposure limits have been exceeded. Through available software packages the noise dose meter may be able to download its stored data into a computer (Figure 10.7a) and provide a histogram of the worker's exposure, an example of which is shown in Figure 10.7b.

Figure 10.6 Personal noise dose meter: correct microphone fitting relative to position of ear
Courtesy B. Groothoff

Figure 10.7a, b Downloading a histogram of a worker's exposure
Courtesy B. Groothoff

All measurements must be made in accordance with measuring protocols recommended by the manufacturer and as required by the relevant Australian Standards®, that is, AS/NZS 1269 for occupational noise and AS 1055 (Standards Australia 1997) for environmental noise.

10.6.3 CALIBRATION

Both the sound level meter and the personal noise dose meter will require calibration with a field calibrator immediately before and after a noise survey in accordance with the manufacturer's instructions. Most calibrators generate a pure tone of 1000 Hz and typically produce a sound pressure level of 94 dB. These parameters are chosen so that the calibrator can be used with the different weightings, as the A weighting, C weighting and linear, all intersect at 1000 Hz. The sound pressure for 94 dB is 1 Pascal.

10.7 ADDING OF SOUND LEVELS

When two noise sources operating side by side have been measured separately, their combined effect can be found using the addition method of Table 10.2. Because decibels are logarithmic values, the individual noise levels cannot simply be added together.

As an example, if two sources were measured at 90 dB and 93 dB, their combined sound pressure level can be found by taking the difference between 90 and 93, which is 3; looking up this value in the left-hand column of Table 10.2 and finding the corresponding correction value in the right-hand column, which is 1.8. Because the two sources operate side by side their combined value must be higher than the highest individual value (93), and the outcome is therefore 93 + 1.8 = 94.8 dB, which can be rounded to 95 dB. Where the difference between two sources is 10 or more, it is generally considered that the lower of the two does not contribute to the higher value. For instance, one source at 85 dB(A) and one at 95 dB(A) will have a combined sound level of about 95 dB(A). Where there are more than two sources operating with a difference of 10 dB or more, their combined level may be affected and needs to be determined by using Table 10.2. This may be the case with items of plant starting and stopping intermittently but which on occasion may all run at the same time and cause exposure limits to be exceeded.

Table 10.2 Logarithmic addition of noise levels

Difference in dB value	Add to the higher dB value
0	3.0
1	2.6
2	2.1
3	1.8
4	1.4
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10.0	0.4
11.0	0.3
12.0	0.2
13.0 or more	0

With a sound level meter, the actual sound pressure level can be measured and confirmed when the sources are generating noise simultaneously.

10.8 DAILY NOISE EXPOSURE

Because workers usually have different noise exposures from different tasks, each lasting different times, it is helpful to have a means of integrating all these exposures into a single, useful noise exposure value. AS/NZS 1269 uses the '8-hour equivalent continuous A-weighted sound pressure level' ($L_{Aeq,8h}$) and the 'A-weighted noise exposure' ($E_{A,T}$) in Pa^2h to express a worker's exposure to noise in a single numerical value. Modern OH&S legislation limits a worker's 8-hour unprotected exposure to $L_{Aeq,8h}$ 85 dB(A). Traditionally the 8-hour allowable exposure has been expressed as a daily noise dose (DND) with a value of 1.0; in other words, a DND of 1.0 is equal to $L_{Aeq,8h}$ 85 dB(A).

As sound propagates from its source it causes small disturbances in atmospheric pressure. The static atmospheric pressure is 10^5 Pa and audible pressure variations are in the order of 20 μPa (20×10^{-6} Pa) to 100 Pa. As we saw in Section 10.4, 20 μPa corresponds to the threshold of hearing and 100 Pa to the threshold of pain. The magnitude of the disturbance is measured with a sound level meter as sound pressure level. The sound level meter measures the square of the relative value of the sound pressure in Pascal over a time period T. The result is expressed in Pa^2 and if present for 8 hours is expressed as Pa^2h (Pascal squared hours). A sound pressure level of

85 dB(A) corresponds to a sound pressure of 0.126 Pa. For an 8-hour work period, the Pa^2h value would be 8 × 0.126 = 1.008 Pa^2h. For practical purposes the $E_{A,T}$ value of 1 Pa^2h corresponds to $L_{Aeq,8h}$ 85 dB(A). It follows therefore that:

$$1\ Pa^2h = L_{Aeq,8h}\ 85\ dB(A) = DND\ 1 \qquad \text{(Equation 10.2)}$$

As the noise exposure level increases, the permitted time of exposure for unprotected ears decreases. This is shown in Table 10.3 as 8 hours of continuous exposure at 85 dB(A), or 4 hours at 88 dB(A), and so on. The 'doubling of sound intensity exchange rate' used by Australian authorities is 3 dB.

Table 10.3 Period of maximum exposure for various equivalent continuous noise levels

Limiting dB(A)	Maximum exposure period allowed to stay within $L_{Aeq,8h}$ 85 dB(A)
85	8 hr
88	4 hr
91	2 hr
94	1 hr
97	30 min
100	15 min

Both the daily noise exposure and Pascal square hours methods provide for the integration of partial noise exposures over an 8-hour period, or over any other period, and enable normalisation of partial noise exposures to a 5-day working week where the worker may work other than 5 days. Modern integrating noise dose meters will have capabilities to calculate the daily noise dose, $L_{Aeq,T}$, $L_{Aeq,8h}$, and $E_{A,T}$ daily exposure in Pa^2h (Pascal squared hours), and method of integrating the noise exposure, built into them. AS/NZS 1269.1 (Standards Australia 2005b) provides the appropriate tables to convert noise level measurement results to Pascal squared values, and relatively simple tabular methods of converting the summed Pascal squared values to an equivalent $L_{Aeq,8h}$.

It should be remembered that these exposures are determined for workers who are not wearing hearing protective devices. A worker wearing hearing protectors in a noisy workplace is in a situation of protected exposure provided the worker is wearing the hearing protectors correctly and consistently. Of course this cannot always be guaranteed. Note also that protected exposure does not mean no exposure.

For shifts exceeding 10 hours there is a greater risk of hearing damage than that posed by noise levels normalised to an 8-hour shift. This is partly because of the additional damaging effect of continued exposure once the maximum temporary threshold shift is reached after about 10 hours of exposure, and partly because of the reduced recovery time between shifts. Corrections must therefore be made to the noise exposure levels to accommodate the greater risk. AS/NZS 1269.1 incorporates in

Clause 9.4 a correction table, reproduced below as Table 10.4, which indicates the adjustments to be made to the normalised exposure level with extended shifts.

Table 10.4 Correction table for extended shifts

Shift length, h	Adjustment to $L_{Aeq,8h}$, dB
<10	+ 0
>10 to <14	+ 1
>14 to <20	+ 2
>20 to 24	+ 3

Source: Standards Australia (2005b)

Use of the correction table can be demonstrated by the following: a worker works a 14-hour shift and is exposed during this shift to $L_{Aeq,14h}$ 89 dB(A). The normalised total daily noise exposure therefore is:

$$L_{Aeq,8h} = 89 + 10 \log_{10} (14/8) = 91.43 \text{ dB(A)} \qquad \text{(Equation 10.3)}$$

For a shift duration of 14 hours, 1 dB must be added. The adjusted $L_{Aeq,8h}$ therefore becomes 92.43 dB(A).

This value must be used in planning for noise management.

10.9 NOISE CONTROL STRATEGIES

If the results of a noise survey identify the likelihood of exposure to excessive noise, further investigation is necessary to identify noise sources and prioritise control strategies to reduce the hazard. Workplace noise control strategies fall into three categories and are indicated here in order of most effective to least effective:

- **Engineering-out** the noise hazard (*source* of noise)
- **Attenuating** the noise hazard (*transmission* of noise)
- Use of **hearing protection** programs (*reception* of noise)

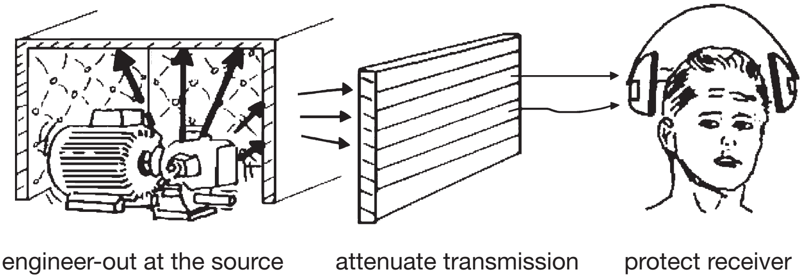

Figure 10.8 Essential elements to be addressed in noise control strategies

1 Control at source: elimination or modification of noise source or process
2 Control of transmission path: enclosures, barriers, machine mountings, sound proofed control rooms, room sound absorbers, etcetera.

Hearing protectors should not be seen as a noise control device but rather a temporary way of minimising a worker's noise exposure by reducing the noise that enters the ear canal.

Occasionally, the H&S practitioner may need to use two or even all three approaches. Attacking the source of the noise or preventing its transmission is always preferable to committing workers to wearing hearing protection. In practice it is often difficult to enforce hearing protection programs. Reliance on the use of hearing protectors by workers will in the long run outweigh the cost of other controls. The cost of many (engineering) noise reduction programs, although perhaps initially expensive, can be surprisingly cheap in the long run, and will remain consistently effective. Some excellent practical examples can be found in Section 10.15, References. Hearing protection should be used only if the alternatives are not possible, reasonably practicable or economical, or as an intermediate phase until more permanent noise reduction measures are in place.

10.9.1 ENGINEERING CONTROLS AGAINST NOISE HAZARDS

Many noise hazards arise because no thought has been given to processes or to correct design or installation of equipment. High levels of continuous and impact noise are often traded off for immediate ease of operation, for example, hammering on metal to bend it rather than bending it with a machine or lever. Noisy motors, compressors, power saws and grinders can all be found in many workplaces, located near work stations, with little regard to their impact on the work environment.

The following examples illustrate some of the principles of minimising or preventing noise being generated.

Substitution of processes

- Use welding instead of riveting.
- Use hot working of metals instead of cold forging.
- Use impact-absorbing materials (plastic, rubber, nylon, etc.) rather than metals.
- Use of procedures such as lowering rather than dropping.

Minimising changes in force, pressure or speed which produce noise

- Eliminate impact noises, for example, use compression rather than impact riveters.
- Replace hammers with slow application of force (Figure 10.9).
- Use hydraulic presses rather than mechanical impact presses.

Reducing the speed

The higher the speed, the higher the frequency and so the louder (as perceived by the ear) and potentially more damaging the noise. To alleviate this:

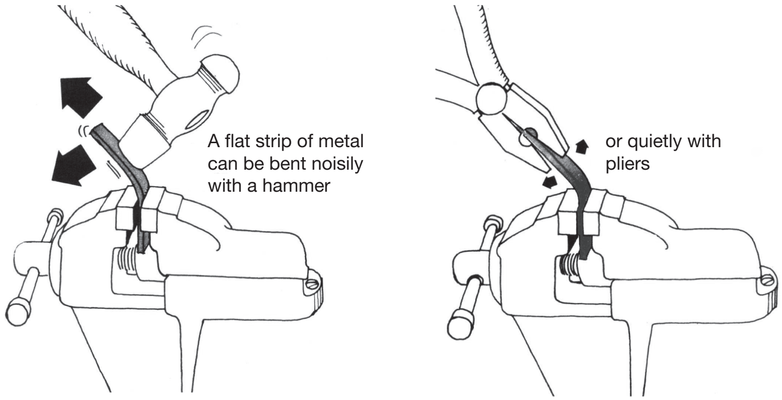

Figure 10.9 Changing the force, speed or pressure to reduce noise
Source: US Dept of Labor

- Use larger, slower machines rather than small, fast ones.
- Run machines at lower speeds, but with higher torque.
- Airguns with air channels around the central channel reduce noise by not having all the air concentrated at high speed through the central air channel but spreading the flow of air through several channels around the central orifice at lower speed while not reducing the effectiveness. The airgun on the left in Figure 10.10 has air channels around the central orifice. This lowers the speed of the air and changes the pitch of the sound. This type of airgun can be up to 7 dB quieter than the 'traditional' airgun shown on the right.

Figure 10.10 The left airgun spreads airflow around the central orifice and is quieter than the 'traditional' airgun on the right
Courtesy B. Groothoff

Prevent mechanical vibration being converted into sound-generating sources

- Isolate the vibrating unit to prevent it from transmitting noise.
- Optimise rotational speed (usually decreasing speed) to prevent oscillating vibrations.
- Alter size or mass to change resonant (i.e. natural) frequencies. Depending on their composition, size and shape, all objects tend to vibrate more freely at a particular frequency. This is called the resonant frequency. A machine transfers the maximum energy to an object when the machine vibrates at the object's resonant frequency.

- Dampen resonance. A ship's engine running at 125 rpm and directly connected to the propeller shaft is shown in Figure 10.11. This speed coincides with the resonant frequency of the propeller shaft and causes disturbing noise and vibration. By incorporating a reduction gear (as shown in Figure 10.11) the propeller shaft now runs at 75 rpm, shifting the vibration to a lower frequency and thus reducing noise.

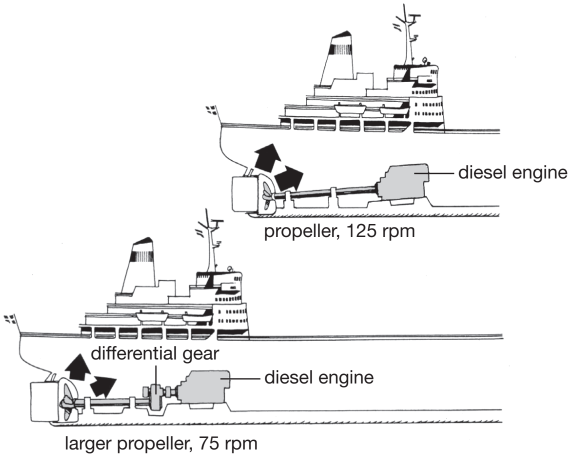

Figure 10.11 Dampening of resonant surfaces to reduce noise generation
Source: US Dept of Labor

- Use extra support or stiffeners to withstand vibrations. The circular saw sharpening machine in Figure 10.12 causes an intense resonant (ringing) noise. By clamping the rubber sheet against the saw blade the resonance and thus the ringing noise is greatly reduced.

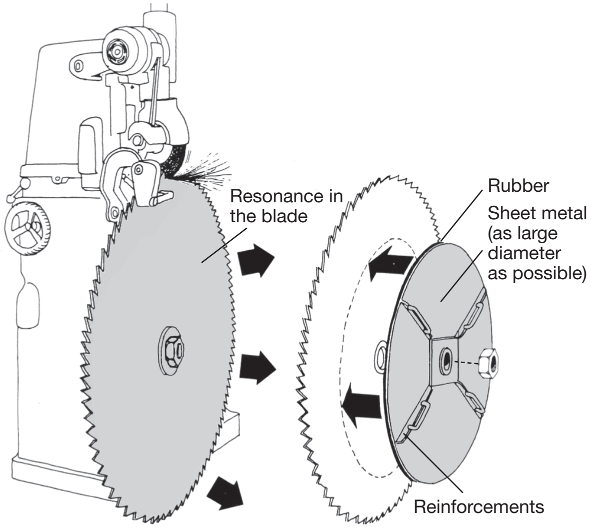

Figure 10.12 Stiffening of resonant surfaces to reduce noise generation
Source: US Dept of Labor

- Use vibration dampening surfaces (Figure 10.13). Steel plates have very poor internal vibration damping. By adding coatings of intermediate layers with better damping properties a reduction in vibration, and thus noise, can be achieved.

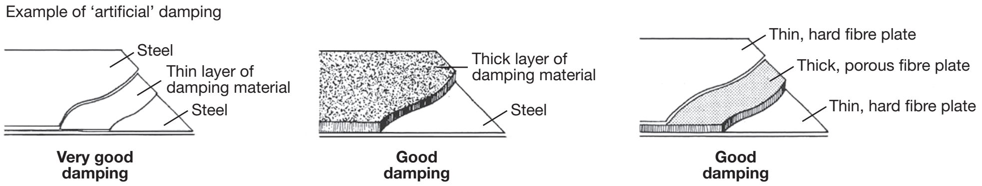

Figure 10.13 Various constructions for vibration dampening
Source: US Dept of Labor

- Reduce radiating area (Figure 10.14). The control panel on the left is mounted on the pump system and vibrates with the system. By isolating the control panel (as shown on the right), the vibrating surface of the system is reduced and therefore the noise level is decreased.

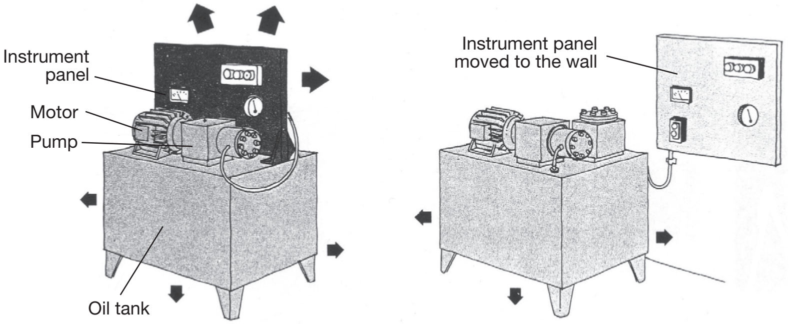

Figure 10.14 Reducing radiating area
Source: US Dept of Labor

- Use perforated non-resonant surfaces (Figure 10.15). On the left, the guard over the flywheel and belt consists of a solid metal cover. This causes the large surface area of the guard to vibrate and act as a sounding board for noise. By replacing the guard with a perforated one (as shown at right) the vibration is reduced and in turn the noise is reduced.

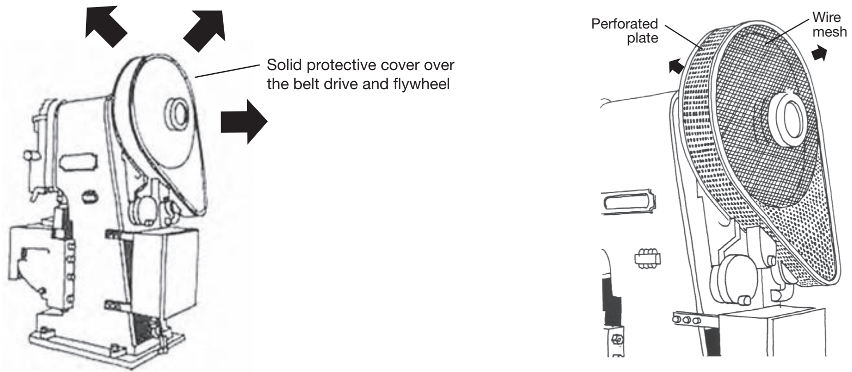

Figure 10.15 Use of non-resonant surfaces
Source: US Dept of Labor

- Use active cancellation (artificial noise created 180 degrees out of phase) to negate the effect of original source.

Reduce transmission possibilities

Fluid pumping systems may be major sources of noise resulting from the intense pressure shocks created in the liquid from the compressors driving the systems. If such systems are mounted rigidly to a building structure, noise can travel through the building and cause problems for the occupants. To avoid noise problems, compressors and pipe systems should be isolated from the building. As shown in Figure 10.16:

- use springs, dampers, flexible couplings and mountings
- ensure ducts cannot carry sound.

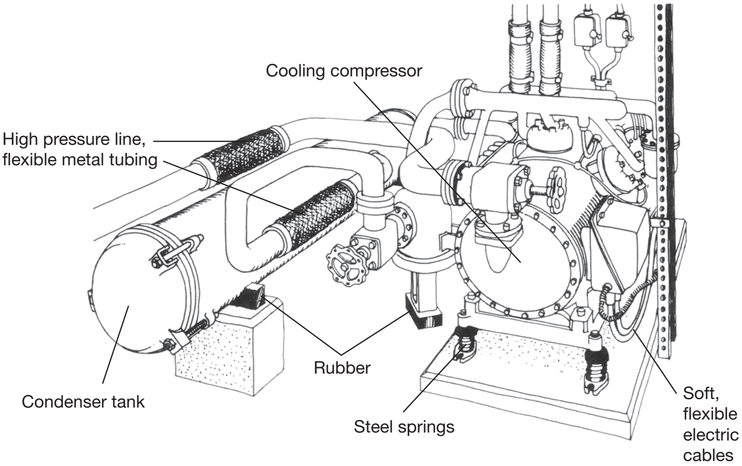

Figure 10.16 Use a flexible connector to decouple noise source
Source: US Dept of Labor

Reduce the possibilities of noise being generated in air or fluid flow

- Use properly designed fans to reduce air turbulence. The air reaching a fan's rotor must be as unobstructed as possible to achieve quiet operation.
- Slowly reduce speed of air or fluid flow to avoid turbulence due to sudden change in volume and pressure drop.
- Use reduced pressures and velocities (Figure 10.17).
- Prevent rapid pressure change which produces 'cavitation' sound (left side of Figure 10.18) resulting from rapid pressure drops near control valves, propellers and pumps. To avoid cavitation noise, selected inserts could be placed in the fluid line so that the insert will not produce a greater pressure drop than required to prevent cavitation (see right side of Figure 10.18).
- Reduce turbulence on air exits (Figure 10.19). When the high speed exhaust air escaping from the grinder's handle mixes with the relatively still outside air the turbulence creates noise. By inserting a silencer consisting of a porous sound-absorbing material the turbulence is broken and the exhaust noise is reduced.

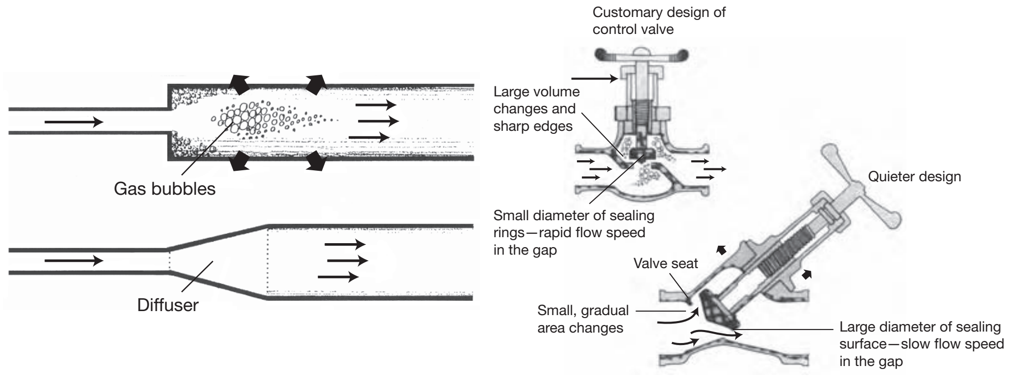

Figure 10.17 Slowly reducing pressure reduces noise transmission in liquids
Source: US Dept of Labor

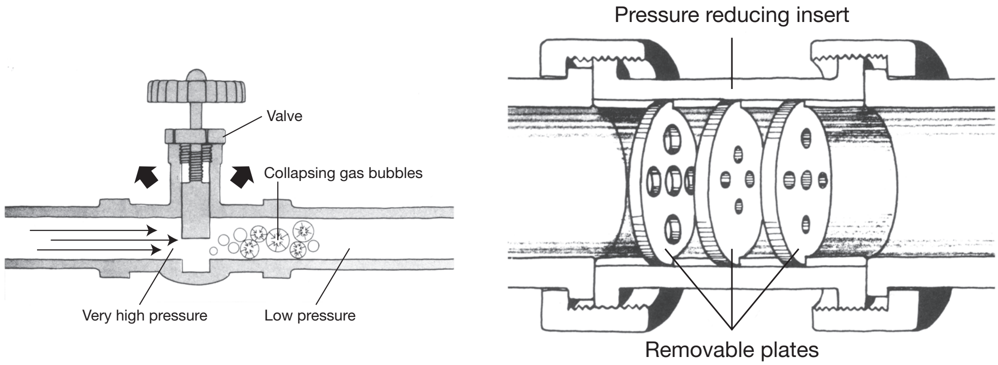

Figure 10.18 Use pressure reducers to reduce ‘cavitation’ sound
Source: US Dept of Labor

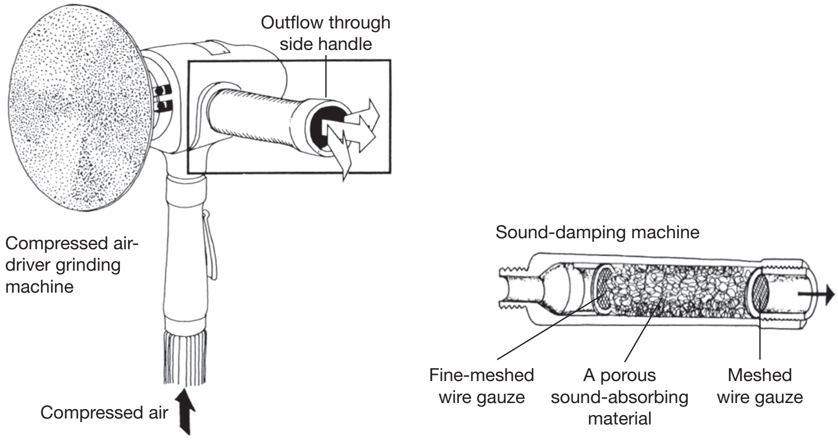

Figure 10.19 Minimising turbulence at air exits to reduce noise
Source: US Dept of Labor

Buy quiet

Noise control techniques should be incorporated in the design and installation of equipment, since the cost of installing noise control at the design and installation stage is minimal compared to aftermarket design and installation. However, there is rarely an off-the-shelf solution for the suppression or control of noise, and it is necessary for the H&S practitioner to assess each workplace situation separately.

- While a piece of equipment may correctly claim to produce sound levels less than 85 dB(A), two or more operating side by side may still produce combined sound levels in excess of the regulatory noise level.
- Companies should be advised to include noise limits in purchasing specifications, keeping in mind the additive effects of more than one piece of equipment. If enough H&S practitioners and employers insist on quiet machinery, manufacturers will begin to provide it.

A good example of 'buying quiet' is the German Blue Angel program, under which manufacturers of construction industry machines and equipment rush to have their products tested to meet the environmental noise criteria. If their products meet the criteria they are entitled to carry the Blue Angel logo. From the manufacturer's perspective this is a selling point, as German (and other European) building sites must comply with strict (local) government regulations and therefore quiet plant and equipment are demanded in requests for tender.

10.9.2 CONTROL OF NOISE TRANSMISSION PATH

The location of a machine or process is often a significant factor in the noise it can transmit to the workplace. Several methods are widely used in workplace noise attenuation.

Isolating the noise source from the worker

If it is concluded that noise generation cannot be prevented, the following options can be tried:

- Locate the noise source remote from the workplace, for example locating pumps, compressors, generators, etcetera outside the building (provided this does not lead to environmental noise complaints).
- Use enclosures around the noise source (see Figure 10.20).
- Confine sources to a noise-insulated room, using double walls with insulating material, double-glazed windows and solid core doors.
- Use an isolating enclosure around the worker.

Noise can be reduced by preventing much of it reaching the worker

- Place noise sources away from natural reflectors, for example in corners.
- Use sound absorbers on ceilings and walls (see Figure 10.21).
- Use noise baffles or deflectors to direct noise away from workers.

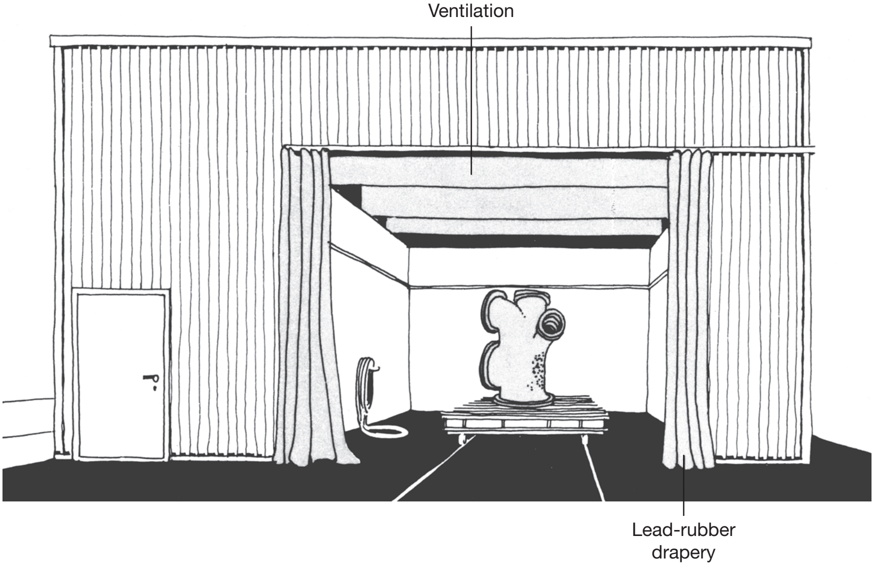

Figure 10.20 Use an isolated room for noisy operations
Source: US Dept of Labor

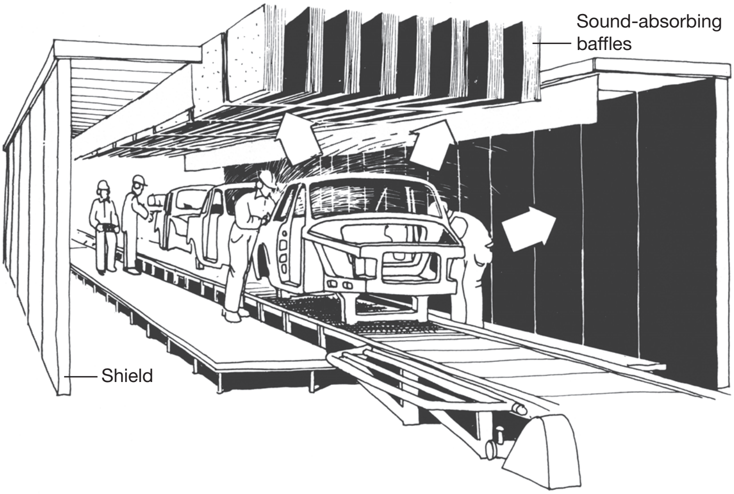

Figure 10.21 Sound-absorbing baffles to minimise sound movement indoors
Source: US Dept of Labor

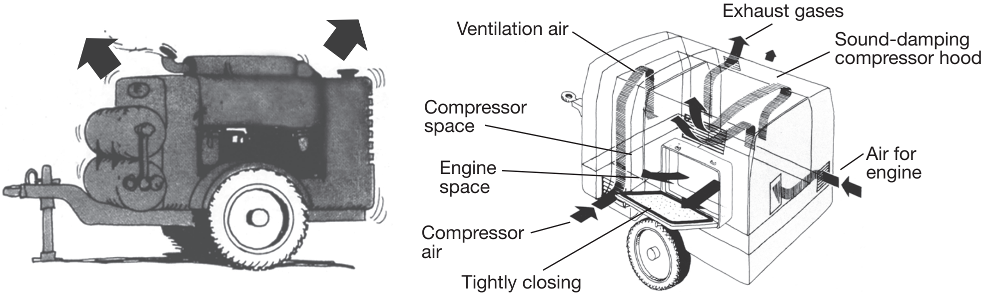

Figure 10.22 Use of sound absorbent to reduce sound transmission
Source: US Dept of Labor

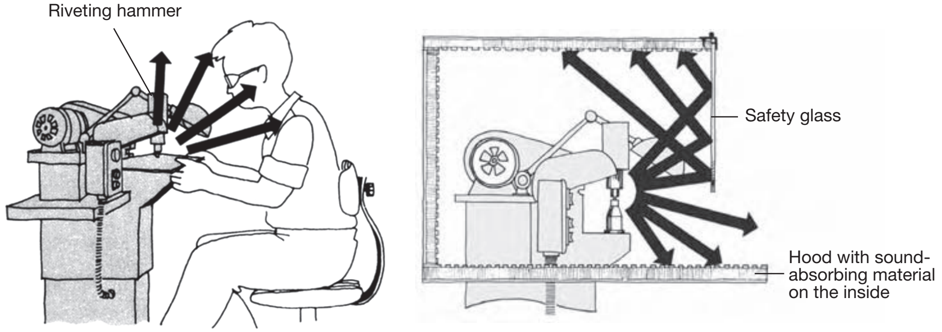

Figure 10.23 High frequency noise can be easily deflected away from the worker
Source: US Dept of Labor

The efficacy of this method depends on frequency. Low frequency noise tends to pass through openings and around objects (see Figure 10.21), while high frequency noise is more easily deflected (see Figures 10.22 and 10.23).

10.10 PERSONAL HEARING PROTECTION

Where it has been confirmed that workplace noise levels are in excess of any regulatory noise limits, for example $L_{Aeq,8h}$ 85 dB(A), and other noise reduction programs such as those above cannot be (fully) implemented, personal hearing protective equipment (HPE) must be used until such time that the noise exposure has been reduced to below the regulatory limits.

To have any chance of success, implementation of a hearing protection program requires complete management involvement and cooperation. From a management perspective, the program must demonstrate that a risk management process has been carried out. The program must at least have such elements as:

- a noise control policy
- a system for conducting noise level and noise level exposure surveys on a regular basis
- a program for the planning and implementation of engineering and administrative noise control, where possible
- a suitable hearing protection training program, including refresher training, and records of training topics and attendance
- continuous supervision and corrective actions by line management to ensure correct fitting of earplugs to ensure attenuation is maximised
- provision of personal hearing protectors and documented reasons as to why the selected hearing protectors were the most suitable
- provision for the use, maintenance, care and storage of the hearing protectors
- provision for audiological assessment of workers on commencement of employment (or the hearing protection program) and regularly thereafter
- ongoing monitoring and review of the effectiveness of the program.

AS/NZS 1269 (Standards Australia 2005d) provides further guidance on the elements and training requirements for the management of workplace noise through noise control management and hearing conservation programs.

Workers and management also need to be totally involved in the program and be trained and educated in the following:

- how the ear works, including how hearing loss occurs
- reasons why hearing protection is required; that is, importance of preservation, of legislation and limitations, and of other control options
- selection of personal hearing protectors
- fitting and use of hearing protectors, comfort
- good and bad habits of wearing hearing protectors
- wearing requirement for using the hearing protectors *all the time* when exposed to noise
- correct use and maintenance of hearing protection.

The H&S practitioner will find that effective hearing protection programs are far from simply buying earplugs or earmuffs for workers. Any chosen earmuff or earplug will, just like a pair of shoes, not fit everyone or be comfortable for everyone. Different types of hearing protectors have different noise attenuation capabilities and may not necessarily be compatible with all work situations. The choice of hearing protectors depends on factors such as:

- the noise levels determined in the workplace
- the frequency spectrum of the noise
- the attenuation required to achieve compliance with regulations
- the worker's hearing ability
- the worker's acceptance of and the degree of good fit and comfort of the hearing protector. An earplug should be inserted for at least half of its length to achieve the rated attenuation
- compatibility with other personal protective equipment
- the need to communicate with others and to hear important signals and sounds
- cost.

10.10.1 TYPES OF HEARING PROTECTORS

There are basically four types of hearing protectors available, of which only two are in widespread use.

Acoustic helmets

These cover a large part of the head and the outer ear, such as those worn, for instance, by helicopter and jet fighter pilots. These helmets are bulky, expensive and not for general industrial use. Noise attenuation may be as much as 50 dB at the lower frequencies, 35 dB at 250 Hz, and it may also diminish bone conduction.

Ear canal caps

Ear canal caps (Figure 10.24) are made from a light rubber or PVC type of material and seal off the entrance to the ear canal without entering it like an earplug does. Ear canal caps are held in place by a spring headband. Ear canal caps are gaining popularity on construction sites due to their ease of positioning over the ears when the worker is faced with noises usually of short duration and which can start suddenly and unannounced.

Figure 10.24 Selection of ear canal caps
Courtesy B. Groothoff

Earplugs

Earplugs (Figure 10.25) are widely used, both as single-use disposable types and re-usable types. They are typically manufactured from foam rubber, plastic or silicone, and may come user-formable, premoulded or custom-moulded. All these types can provide good noise attenuation, but attention has to be paid to correct fitting. All are designed to prevent noise reaching the inner ear by being placed directly into the ear canal. The formable types are designed to fit all ears; they are rolled between the thumb and finger into a cylindrical shape prior to insertion and held in place with the thumb or finger until they expand to block the ear canal.

Figure 10.25 Selection of earplugs
Courtesy B. Groothoff

Reusable earplugs (Figure 10.26) should be able to be inserted in the ear canal without having to be squashed to fit. Some premoulded earplugs have an acoustic resonator chamber included to provide an almost flat attenuation across the frequency range. This type of earplug may be beneficial for workers who have a higher demand for communication via noise, or who have a mild hearing loss, as the attenuation at 2 and 4 kHz (4 kHz is where NIHL typically manifests itself) is not as great as with normal industrial type earplugs.

Figure 10.26 Example of a reusable flat attenuating earplug
Courtesy B. Groothoff

Individually moulded earplugs are made from an acrylic or silicone mould of the wearer's ear canal. This means that the earplug can only be worn in the ear canal for which the mould was made. Individually moulded earplugs can also be fitted with acoustic resonator chambers to provide an almost flat attenuation over the frequency range, and can therefore assist in communication by offering less distortion than ordinary individually moulded earplugs. Individually moulded earplugs must be expertly fitted since performance and comfort may be poor if they are ill-fitting either in design or size. An example is shown in Figure 10.27.

Figure 10.27 Individually moulded earplugs with resonator chambers fitted
Courtesy B. Groothoff

Earmuffs

These are also very common, and consist of two padded and internally insulated domes which cover the entire ear (see Figure 10.28). A spring-torsioned headband holds the padded cups to the side of the head at a clamping force to provide the attenuation desired. When selecting earmuffs, ensure that the cup is just large enough to clear the ear lobes. It is important that the cushions attached to the cups are soft and not cracked as they are essential in providing a proper seal. They should be cleaned after use and their condition regularly checked. When hard or cracked they can be easily replaced without having to replace the earmuff.

In situations where communication via noise is important, so-called noise cancelling earmuffs can be used. These types of earmuffs have either mechanically or electronically activated shut-off valves which enable the earmuffs to allow noise up to a certain level, usually 82 dB(A); through and above this level the muff operates as a proper earmuff.

Another type of earmuff is available with a built-in radio receiver. Although this may seem attractive for workers doing mundane or boring work, the volume of radio sound inside the cup combined with the level of workplace noise entering the cup may

Figure 10.28 Earmuff hearing protector
Courtesy B. Groothoff

cause the 8-hour exposure limit to be exceeded. An employer providing this kind of earmuff to workers must ensure that the workers' in-ear noise level does not exceed the exposure limits imposed by OH&S legislation.

10.10.2 FREQUENCY ATTENUATION

Sound can be transmitted to the inner ear via bone conduction, leaks in the ear canal seal, oscillation of an earplug, transmission of sound through an earmuff or vibration through a sealing cushion of an earmuff. For these reasons, attenuation of more than 50 dB is not possible. Some types of hearing protectors cannot attenuate low frequencies as well as others. Figure 10.29 compares the typical attenuations of an earplug and an earmuff.

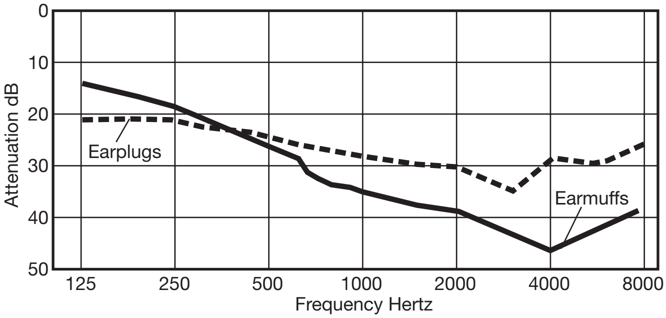

Figure 10.29 Noise attenuation of earplugs and earmuffs

In selecting hearing protection, we have to know which frequencies need to be attenuated. For example, if the noise were predominantly low frequency, a hearing protector which has poor low frequency protection would not be an appropriate choice. On the other hand, a worker might actually need to hear some of the lower frequencies of speech if voice communication is required. Overall, the aim is to ensure that the daily noise exposure of the hearing-protected worker is still less than $L_{Aeq,8h}$ 85 dB(A), irrespective of the frequency spectrum composition of the noise in the workplace.

There are several ways of going about selecting hearing protective devices (HPDs), ranging from a simple crude assessment of the noise to sophisticated assessment which takes account of all the actual frequencies involved. All of them require some workplace noise measurement to be made. Failure to measure the workplace noise runs the risk of either under- or over-attenuation, which can place in jeopardy a worker's hearing or safety respectively. There are several different methods of making the assessment, each with different precision and useful for different purposes.

10.10.2.1 Classification method

The simplest form of selecting an HPD is to use the New Zealand classification method, as referenced in AS/NZS 1269.3 (Standards Australia 2005d). Selection of the HPD depends on the extent to which the $L_{Aeq,8h}$ is above the critical level of $L_{Aeq,8h}$ of 85 dB(A). For the classification method, a workplace assessment is made using a noise dose level or sound level meter to measure the A-weighted average exposure (or, if no noise dose meter is available, some other equivalent measure such as $L_{Aeq,T}$ from which, based on a knowledge of workplace activities and work histories, an 8-hour exposure can be calculated). Selection of the appropriate hearing protector class is then made from Table 10.5.

This method suits those H&S practitioners who can measure only an A-weighted workplace noise exposure. It does not take into account the actual frequency of the workplace noise being measured. It can lead to inappropriate choices if the noise contains predominantly very high or very low frequencies.

10.10.2.2 Sound level conversion method

The sound level conversion (SLC_{80}) method was originally developed as a simplified method from the octave band method. It uses the difference between the C-weighted L_{eq} and the A-weighted L_{eq} reaching the wearer's ear, and therefore accounts better for the low frequency components (<80 Hz) in the workplace noise, as well as the high frequency components (>3150 Hz). The SLC_{80} technique is a simple method for determining the HPD best suited for wearing in a hazardous noise area. It refers to a rating given to hearing protectors which will provide the stated attenuation or noise reduction in 80 per cent of wearers.

The first step is to measure the workplace noise level in dB(C) at the worker's ear (i.e. using the C-weighting network of the sound level meter instead of the A-weighting).

The second step is to calculate the minimum SLC_{80} that an HPD should have in order to provide adequate hearing protection for the wearer. This is determined by simply subtracting the 'desired' A-weighted in-ear noise level of the wearer from the C-weighted noise level measurement result.

The 'desired' wearer's ear noise level is typically chosen to be between 75 and 80 dB(A), a noise level that constitutes minimal risk of NIHL. To enable the wearer of a hearing protector to communicate in the noisy environment the wearer must be able to hear and understand what is being communicated. The HPD therefore must

Table 10.5 Class method for hearing protection

Class	$L_{Aeq,8h}$, dB(A)
1	less than 90
2	90 to less than 95
3	95 to less than 100
4	100 to less than 105
5	105 to less than 110

Source: Standards Australia (2005d)

provide sufficient noise attenuation without blocking too much noise. This means the in-ear noise level should meet at least legal requirements but preferably the target level of between 80 and 75 dB(A). The 'bigger is better' syndrome definitely does not apply here and over-protection should be avoided as much as under-protection. Over-protection leads to feelings of isolation and removal of the protector when communication is required.

All HPDs should, as a minimum, provide information of an SLC_{80} rating, a class rating and an octave band rating. Sometimes the manufacturer will provide an example of how the rating is applied. For example, if the work environment has a C-weighted noise level of 105 dB(C), wearing a hearing protective device with an SLC_{80} rating of 27 dB should provide an in-ear sound level of 105 – 27 = 78 dB(A). An HPD with an SLC_{80} of only 15 dB would permit in-ear noise levels of up to 90 dB(A), proving to be inadequate for use in that noise environment. Table 10.6 shows the relationship between the class and SLC_{80} method of determining suitable hearing protection.

Table 10.6 Relationship between class and SLC_{80}

Class	SLC_{80} range
1	10 to 13
2	14 to 17
3	18 to 21
4	22 to 25
5	26 or greater

Source: Standards Australia (2005b)

10.10.2.3 Octave band method

The third method of measuring frequency attenuation is the more sophisticated octave band method. This method is the most suitable where special noise characteristics in the workplace need to be addressed (e.g. high-pitched noise, or a low frequency component), and must also be applied where the $L_{Aeq,8h}$ exceeds 110 dB(A). It involves conducting a frequency analysis of the workplace noise in which the hearing protector is to be used. The octave band attenuation of the hearing protector is then subtracted from the measured octave band results in the frequency range between 125 and 8000 Hz. Then the A-weighted sound level, as presented to the ear, is calculated for the resulting attenuated spectrum. Application of the octave band method requires a precision sound level meter designed for octave band analysis, because of the need to measure unweighted (i.e. linear) sound pressure levels.

To ensure the hearing protector has appropriate attenuation, two sets of data are required:

- the measured octave band analysis of the noise in the workplace
- the frequency attenuation of the hearing protector, provided by the manufacturer.

CALCULATION OF OCTAVE BAND ATTENUATION

Step 1 Obtain a sound level survey in the workplace, using octave band analysis at the frequencies as shown in the following example. Use unweighted sound pressure levels, i.e. linear (never A- or C-weighted) levels.

This is done by using a sound level meter which has the capacity to record the unweighted sound pressure levels of at least seven different frequency bands centred on the following frequencies: 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz.

Measured octave band levels

Frequency (Hz)	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Octave band level (dB re 20 µPa)	87	88	90	94	97	106	107

Step 2 Obtain the frequency attenuation of the hearing protector.

In each octave, subtract the mean minus standard deviation octave band attenuation of the hearing protector from the measured octave band results.

Attenuation of earmuff

Frequency (Hz)	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Mean minus standard deviation (dB*)	13	13	14	18	25	35	28

* NAL (1998)

Step 3 Calculate attenuated sound levels.

Frequency (Hz)	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Unweighted SPL* (from noise survey)	87	88	90	94	97	106	104
Mean minus standard deviation (dB)	13	13	14	18	25	35	28
Attenuated sound level (dB)	74	75	76	76	72	71	76

* sound pressure level

Step 4 Apply A-weighting corrections and calculate A-weighted attenuated sound levels.

Make the A-weighting correction by adding the A-weighting corrections at the same frequencies. (The origin of the A-weighting correction values was explained in Section 10.4.)

Frequency (Hz)	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Attenuated sound level (dB)	74	75	76	76	72	71	76
A-weighting correction (dB)	–16	–9	–3	0	+1	+1	–1
A-weighted attenuated levels	58	66	73	76	73	72	75

Step 5 Rearrange the A-weighted attenuated sound levels from the highest to the lowest, i.e.:

76, 75, 73, 73, 72, 66, 58

Note: the rearranging of sound levels is done as a matter of course, because when subtracting sound levels you cannot subtract a higher value from a lower.

Then add them two at a time, using the procedure in Table 10.2, until all are used, as follows:

1. From the sound intensity theory we know that two similar noise levels increase their combined level by 3 dB. Therefore 73 + 73 = 76 dB.
2. There is another level of 76, therefore 76 + 76 = 79 dB.

For the other levels we can use the procedure in Table 10.2 to add together the contributions of each of the bands. We start with the highest remaining level, i.e. 75 dB.

1. The difference between 79 and 75 is 4. Looking up this difference in Table 10.2 shows a correction factor of 1.4 to be applied to the higher level. The combined level of 79 and 75 is therefore 79 + 1.4 = 80.4 dB.
2. The next level to use is 72. The difference between 80.4 and 72 is 8.4. Table 10.2 indicates that with a difference of 8 a correction of 0.6 dB is to be applied to the higher level. Therefore 80.4 + 0.6 = 81 dB.

3. The differences between 81 and the remaining sound levels, i.e. 58 at 125 Hz and 66 at 250 Hz, are greater than 13 and therefore do not add to the level of 81 dB.
4. The attenuated level under the earmuff is therefore about 81 dB(A).

This is well within the daily noise dose, $L_{Aeq,8h}$, 85 dB(A), but 1 dB short of the target level of 80 dB(A), provided the worker always wears the hearing protector in this noise environment while exposed to noise.

To combine the attenuated A-weighted values of the hearing protector we can use this formula instead of the correction table:

$$L = 10 \, \text{Log}_{10} \, (10^{L1/10} + 10^{L2/10} + 10^{L3/10} + \ldots\ldots\ldots) \quad \text{(Equation 10.4)}$$

Applying the formula we should get:

$$L = 10 \, \text{Log}_{10} \, (10^{58/10} + 10^{66/10} + 10^{73/10} + 10^{76/10} + 10^{73/10} + 10^{72/10} + 10^{75/10})$$
$$L = 81.2 \text{ dB(A)}$$

This method is more accurate. The difference of 0.2 dB between the formula and correction table method is so small it can be ignored. It shows, however, that the correction table method is pretty accurate.

You will find that reputable manufacturers of HPDs will provide all the details on attenuation at the various frequencies. Alternatively, when the HPD has been tested in accordance with AS 1270 (Standards Australia 2002), you can find the frequency attenuations in *Attenuation and use of Hearing Protectors*, published by the National Acoustics Laboratories (NAL 1998) and available from the Australian Government Publishing Service or the National Acoustics Laboratories. You can then choose from any of the hearing protectors listed, and select the protector which provides adequate protection, according to the determined workplace noise, cost, and wearer compatibility and acceptability.

If you think that hearing protectors may be required in the workplace and you do not have sound level measuring equipment, you could ask a supplier or an acoustic consultant to conduct octave band noise analysis in each noisy location. You can then calculate the expected sound levels for the hearing protectors from the manufacturer's published information to check whether or not the hearing protector will be adequate.

Other information on noise measurement can be found in:

- AS IEC 61672.1 *Electroacoustics—Sound Level Meters, Part 1: Specifications* (Standards Australia 2004b)

- AS IEC 61672.2 *Electroacoustics—Sound Level Meters, Part 2: Pattern Evaluation Tests* (Standards Australia 2004c)
- AS/NZS 1269 Parts 0–4—*Occupational Noise Management* (Standards Australia 2005a; 2005b; 2005c; 2005d; 2005e)
- *Noise Management at Work: Control Guide* (Worksafe Australia 1990).

10.10.2.4 HML method

A fourth method is the HML method, commonly used by European manufacturers and suppliers of hearing protectors. The HML (corresponding to high, medium and low frequency noise reduction of the hearing protectors) method is a simplified approach which claims the same accuracy as the octave band method. The HML method requires measurement of both the C-weighted and A-weighted measurements, and uses a nomogram approach to determine the predicted noise level reduction and the final A-weighted noise level which the ear would receive inside the hearing protector. This method can only be used if the manufacturer has specified the HML values for the protector and you can measure both the C- and A-weighted sound levels simultaneously. It is a useful method for the H&S practitioner wanting to provide hearing protection better tailored to the noise profile of the workplace and armed with a sound level meter of modern sophistication.

10.10.2.5 NRR method

The NRR method is an American system of determining the expected attenuation of a hearing protector. This method cannot be used in Australia or compared to, say, SLC_{80} values, because of the different laboratory test method used in the United States and the different exchange rate for doubling of sound intensity. The United States uses a 5 dB exchange rate whereas Australia, and most other countries, use the natural 3 dB rate.

10.11 INDUSTRIAL AUDIOMETRY AND THE HEARING CONSERVATION PROGRAM

Industrial audiometry, the testing of workers' hearing acuity, may well identify hearing disabilities. Such tests may not necessarily indicate, however, that hearing loss is the result of current noise exposure.

Audiometry is not generally a task for the H&S practitioner. It requires well-trained, qualified, experienced personnel with properly calibrated test equipment and a specially constructed soundproof booth. To prove useful, it must be part of an ongoing program. Hearing is regularly tested, preferably from the time the worker joins the workplace, to observe if there is any discernible deterioration in hearing above that which is expected from loss due to ageing (presbycusis).

A health practitioner trained in conducting hearing tests (an audiometrist or audiologist), will test the worker's baseline auditory threshold, for both ears. The frequencies used for both reference and monitoring audiometry are 500 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz and 8000 Hz.

Reference audiometry must be conducted as soon as possible after commencement of employment, but should ideally be conducted before exposure to a noisy workplace occurs. Audiometric testing must be performed immediately after a period of not less than 16 hours of quiet. Noise exposures below 75 dB(A) are unlikely to produce temporary threshold shift.

Monitoring audiometry should be performed within 3 months and then 12 months of the initial work exposure for comparison with the results of the reference audiometry. If there is no significant change in threshold shift or in the work situation, it may then be sufficient to retest at yearly intervals or as prescribed by OH&S legislation. For workers exposed to high exposure levels, >100 dB(A), more frequent audiometric testing may be required. Monitoring audiometry should be scheduled to take place well into the work shift so that comparison can be made with the results of the reference audiometric test. This will reveal any temporal threshold shift due to inadequacies in the use of personal hearing protectors.

Where significant hearing impairment is detected at the initial reference audiometric test, the person should undergo a medical examination if a repeat test, conducted on another day, confirms the original finding.

Where the monitoring audiometry results, when compared with the results of the reference audiometry, show:

1. a shift in average threshold at 3000, 4000 and 6000 Hz greater than or equal to 5 dB; or
2. a shift in mean threshold greater than or equal to 10 dB at 3000 and 4000 Hz; or
3. a change in mean threshold greater than or equal to 15 dB at 6000 Hz; or
4. a threshold shift greater than or equal to 15 dB at 500, 1000, 1500 or 2000 Hz; or
5. a threshold shift greater than or equal to 20 dB at 8000 Hz

then the worker should be requested to have further audiometric examination on another day after 16 hours in quiet conditions. If a shift is confirmed during this second test, the person should be referred for a medical opinion. If the shift in threshold is confirmed as noise induced, the person should be advised of this in writing. Figure 10.30 shows the various degrees of hearing loss and their relationship to everyday sounds as shown in the scale on the right.

Audiometric testing can be of benefit to both employers and workers in excessively noisy industries (foundries, canneries, metal industries, air transportation), but only if it is an integral part of a rigorous hearing conservation program. Audiometric testing in isolation from other elements of a hearing conservation program only serves to record the deterioration in hearing. In combination with other elements it can detect the early onset of NIHL and enable counter-measures to be put in place. The tests may also provide useful information for assisting in workers' compensation claims. For instance, an employer who knows the hearing ability of workers at the commencement of their employment and can demonstrate adherence to a robust hearing conservation program may well have a defence against future claims for NIHL compensation.

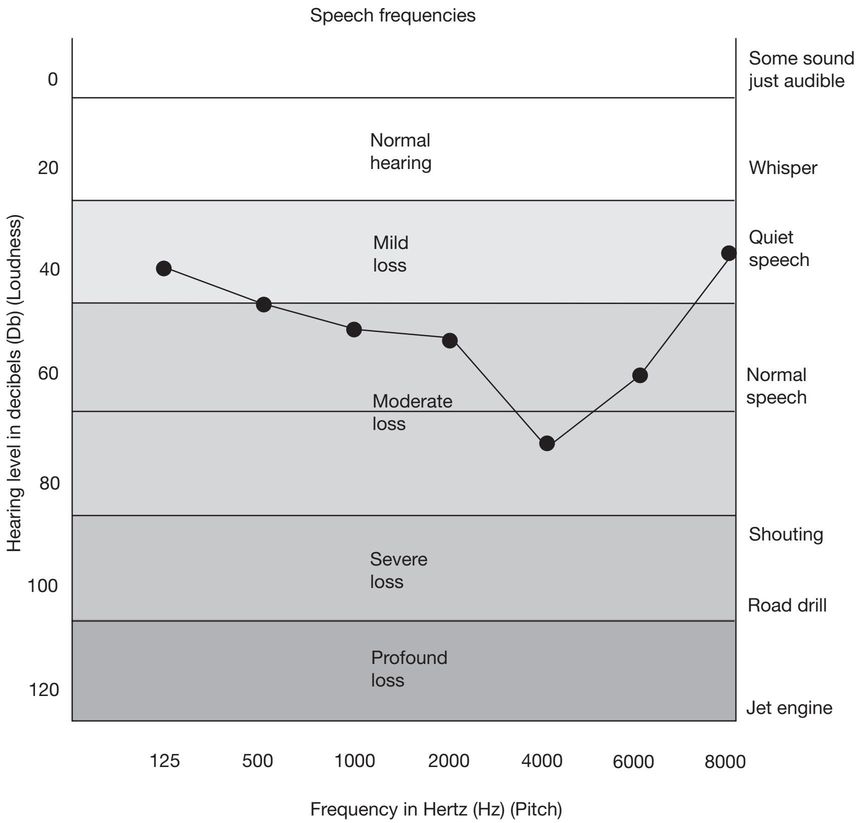

Figure 10.30 Showing various degrees of hearing loss
Courtesy B. Groothoff

Hearing conservation programs are designed to prevent long-term hearing impairment, principally by maintaining noise exposure within the limits required by the legislation. Any of the technical control processes discussed above might be used in such a program. Certainly, the best are noise reduction programs. However, if noise sources cannot be quietened sufficiently, the worker must become involved by using an HPD. Management's commitment to training and proper education of the workforce in the purpose, use and benefits of HPDs must be matched by the rigid enforcement of such programs.

10.12 ACOUSTIC SHOCK

10.12.1 INTRODUCTION

ACIF G616 *Industry Guideline—Acoustic Safety for Telephone Equipment* (Standards Australia 2006), defines an **acoustic incident** as:

> The receipt by a telephone user of any unexpected sound that has acoustic characteristics that may cause an adverse reaction in some telephone users. Depending on the characteristics of the sound and of the user, an acoustic shock may result from the incident.

An acoustic incident is typically a high intensity, high frequency monaural squawk, screech, shriek or howling tone, occurring without warning. This type of noise is typically produced by such things as misdirected fax calls, sometimes feedback between the microphone and the speaker of the telephone, or mobile phone signal interference.

Exposure to an acoustic incident usually does not last more than a few seconds, as the operator would tear off the headset almost as soon as the signal was heard. An acoustic incident may, however, if severe enough, lead to acoustic shock.

Acoustic shock is defined by the European Telecommunications Standards Institute (ETSI 2000) and ACIF G616 (Standards Australia 2006) as:

> Any temporary or permanent disturbance of the functioning of the ear, or the nervous system, which may be caused to the user of a telephone earphone by a sudden sharp rise in the acoustic pressure produced by it.

Tests have shown that the signals are less than 120 dB sound pressure level at the eardrum. This is due to the electronic limiters in the headset systems. Measurements by the Health and Safety Laboratory of the UK Health and Safety Executive (2001) indicate that fax tones produce on average 83 dB(A), holding tones 88 dB(A) and carrier tones 95 dB(A) when measured at maximum volume.

10.12.2 HOW IS AN ACOUSTIC SHOCK EXPERIENCED?

When an acoustic incident occurs, initially a startle or shock reaction may be experienced. In extreme cases operators may quickly experience a varied combination of vertigo, nausea, vomiting, stabbing pain in the ear, feeling of fullness in the ear and/or facial numbness. Tingling, tenderness or soreness around the ear and neck and arms, and tinnitus, may also be experienced. There is seldom loss of hearing and symptoms tend to disappear over time.

Secondary and tertiary symptoms may develop, consistent with stress from trauma, including headache, fatigue, feelings of vulnerability, anger, hypervigilance and hypersensitivity to loud sound, depression, substance abuse and anxiety, especially about return to work.

10.12.3 WHY CALL CENTRES?

An explanation for the symptoms experienced by a call centre telephone operator after an acoustic incident must be sought in the psychosomatic and physiological areas. The main psychosomatic factors are stress caused by the work pressures of handling large volumes of telephone calls within certain time limits, the performance monitoring systems applied and targets to be achieved, management culture and the operator's perceived lack of control over the stressful work situation, and the inability to anticipate the occurrence of an acoustic incident. Furthermore, the work environment, with often inadequate office equipment and acoustics, lack of proper training provisions, the technology of modern digital communication means, mistakes by callers such as sending a fax over a telephone line, mobile phone signal interference or deliberate loud noises caused by irate callers, may all contribute. These issues combine to cause stronger physiological responses (e.g. startle reflex) when an acoustic incident does take place than if the worker were exposed to a similar sound in an industry where the sound was anticipated.

The main physiological response mechanism to an acoustic shock is in the middle ear. The middle ear contains two muscles, the stapedius and the tensor tympani, which are attached to the ossicles (the middle ear bones called malleus, incus and stapes). The tensor tympani muscle is attached to the malleus and the stapedius muscle to the stapes. When loud sounds occur both muscles react, causing what is known as the 'aural reflex'. The stapedius muscle reacts to loud sounds causing an increased pressure on the oval window membrane of the cochlea and the movements of the stapes. The tensor tympani muscle causes a startle reflex. If triggered, it restricts the movements of the malleus and incus and is capable of placing large forces on the alignment of the eardrum. The tensor tympani muscle's reflex threshold can be 'reprogrammed' to react at much lower sound levels.

With acoustic shock incidents the loud noises occur with rise times of between 0 and 20 milliseconds. The reaction time for the middle ear muscles to contract is about 25 milliseconds. When they do contract they do so with added force because of the combination of loud noise and the startle reflex. In extreme cases this may lead to a tearing of the oval or round window membrane and subsequent leaking of fluid from the cochlea.

10.12.4 WHAT IS THE EVIDENCE FOR THE EXISTENCE OF ACOUSTIC SHOCK?

The available evidence indicates that acoustic shock and its effects are a real health issue because of the specific characteristics of call centres. In Australia alone there are several hundred reported cases of acoustic shock in call centre telephone operators. A minority of these operators are unable to continue working as telephone operators. Other countries also report acoustic incidents in call centres. The symptoms reported both in Australia and overseas are remarkably similar and therefore the chance of all these cases being due to malingering is nonexistent.

10.12.5 HOW CAN ACOUSTIC SHOCK BE MANAGED?

Management of acoustic incidents must focus on two main areas:

- prevention of sudden loud noises over the telephone through the incorporation of appropriate telephone equipment and electronic sound limiting devices
- the reduction of stress levels in workers, through appropriate workplace design, management systems and worker education.

The two main areas must be implemented in combination, as either one will fail without the other.

10.12.6 PREVENTION OF LOUD NOISES OVER THE TELEPHONE LINES

Telephone systems should comply with AS/ACIF S004 *Voice Frequency Performance Requirements for Customer Equipment* (Standards Australia 2004a) and are thus limited to 120 dB. However, this does not prevent acoustic incidents occurring. To prevent the loud noises entering an operator's headset, a so-called volume-limiting amplifier must be incorporated between the telephone and the headset. Such a device searches for high frequency acoustic tones and eliminates them within about 20 milliseconds. If the device is working correctly the telephone operator is quite often not even aware that a loud tone has occurred.

10.12.7 REDUCTION OF STRESS LEVELS IN CALL CENTRE WORKERS

The two main areas for reducing negative stress are the work environment (including management systems), and the workplace design (including construction, layout and equipment).

OH&S legislation is quite specific about conducting risk assessments for different tasks and systems of work in order to ensure a safe and healthy work environment. It is less specific about workplace design. For call centres it needs to be understood that the acoustics in a given call centre put a limit on the number of operators due to speech interference. Proper acoustic design is therefore beneficial to the owner of the call centre in that it optimises communication and the number of telephone operators. It is also beneficial to the telephone operators because, with better ability to communicate, stress levels will be reduced to acceptable levels which do not interfere with, or otherwise affect, the way the work is intended to be conducted and there will be no detrimental effects on the operator's health.

10.13 OTOTOXINS

10.13.1 INTRODUCTION

A wide variety of chemicals and medication may, alone or in concert with noise, result in hearing loss. These substances are called ototoxins (*oto* = ear, *toxin* = poison) and affect the hair cells and/or the auditory neurological pathways. Inhalation or absorption through the skin of certain chemicals may cause hearing loss independent of noise exposure, while other chemicals may have an additive or synergistic effect. Some chemical toxicants that do not cause permanent hearing loss themselves may, in combination with noise exposure, cause permanent hearing loss. Hearing damage is more likely to occur if exposure is to a combination of substances or to the combination of a substance and noise. Because of the different mechanisms of interaction between noise and ototoxins there are difficulties for both risk assessment and standard setting in the industrial environment. Different professions using a different 'language' in terms of measurement of chemical agents and physical stressors, and the tendency in industry to attribute NIHL in noisy environments to noise alone, confound this further.

Ototoxins can be divided into two general classes—workplace chemicals and medication. In this section medication will only be briefly mentioned. Of the workplace chemicals three major classes have been identified—solvents, heavy metals and chemical asphyxiants.

10.13.2 WORKPLACE CHEMICALS

In the vast majority of cases ototoxic hearing loss is caused by solvents of the aromatic and aliphatic hydrocarbon chains. These solvents have been well recognised for their neurotoxic effects on both the central and peripheral nervous systems. The most common ototoxic solvents are alcohol, toluene, ethyl benzene, styrene, n-hexane, carbon tetrachloride, carbon disulfide, trichloroethylene, perchloroethylene and acrylonitrile. Other known ototoxic substances in the workplace include mercury, manganese, lead, arsenic and cobalt, and asphyxiants such as hydrogen cyanide and carbon monoxide. Carbon monoxide is also released as a metabolic by-product of the paint stripper methylene chloride.

Occupations where noise and ototoxins often combine

Some of the occupations where noise and ototoxic substances are most commonly found together are:

- printing
- painting
- boat-building
- furniture-making
- refinery/petroleum products
- fuelling vehicles/aircraft
- fire fighting
- weapons firing (armed forces, shooting clubs)
- rural/agriculture.

There is still a lot of research being carried out to establish the effects of human exposure-response relationships for workplace ototoxins. One of the problems to overcome is to relate the results of animal studies to humans. Human occupational exposure studies conducted so far seem to complement the laboratory studies and suggest that simultaneous exposure to noise and chemicals produces a significantly greater hearing loss than the sum of either agent acting alone. Even though exposure standards for chemicals and noise have as yet not been altered to take account of increased risk to hearing, it is expected that in the near future it will be possible to predict the interaction of a chemical with noise. It is also expected that the effects of substances by themselves on the auditory system will be better understood and can be used in hearing conservation programs.

Agents that are considered synergistic with noise exposure (i.e. neither the agent nor the noise alone would produce a threshold shift) include carbon disulfide, carbon tetrachloride, carbon monoxide, hydrogen cyanide, styrene, methyl ethyl ketone and methyl isobutyl ketone.

Agents that are considered to have either an additive or synergistic effect include toluene, ethyl benzene, styrene, carbon monoxide and hydrogen cyanide.

Agents that are known to cause auditory system impairment by themselves include:

- organic solvents such as toluene, styrene, xylene and trichloroethylene
- metals such as cobalt, mercury, lead and trimethyltin
- asphyxiants such as carbon monoxide and hydrogen cyanide.

It is recommended that employees working in any of the occupations listed earlier be included in audiometric testing programs. Reviewers of audiometric test program data should be alert to the possible additive or synergistic effects between the exposure to noise and ototoxins. Where necessary they should suggest reducing exposure to one or both agents. Employers should ensure that information on ototoxins and their effects are included in training sessions. It is further recommended that annual audiograms be taken of employees whose airborne exposures to known ototoxic substances (without regard to respiratory protection worn) are at 50 per cent or more of the NOHSC workplace exposure standard for the substance in question, regardless of the noise level.

10.13.3 MEDICATION

Some medications have been identified as ototoxins and include: antibiotics such as streptomycin; quinine; salicylates such as aspirin when used over long periods of time; anti-inflammatory, anti-thrombosis and anti-rheumatic agents, and loop diuretics.

Employees who may have any concerns about the ototoxic effects of medication should be encouraged to discuss their concerns with their doctor or pharmacist.

For further information on ototoxicity issues see Section 10.16, Further reading, for the NIOSH website address.

10.14 VIBRATION

Exposure to vibration is widespread in modern industries. Many tools, machines and vehicles such as chainsaws, jackhammers, chipping tools, tractors and earthmoving vehicles vibrate. Vibration occurs as a side-effect of industrial activities or may be deliberately introduced, for example, in concrete pours, where vibration is used to shake the wet concrete into place.

Prolonged exposure to vibration causes health effects, disorders and/or disease. The risk of contracting any of these depends on the characteristics of the vibration, the part(s) of the body exposed and the duration of exposure.

10.14.1 HUMAN EXPOSURE TO VIBRATION

There are basically three kinds of human exposure to vibrations. These are:

- vibrations transmitted simultaneously to the whole body surface or substantial parts of it. This occurs when the body is immersed in a vibrating medium, for example when high intensity sound in air or water excites vibrations in the body
- vibrations transmitted to the body as a whole through the supporting surface, for example in vehicles, drill platforms or in the vicinity of working machinery, vibration is transmitted through the feet, the buttocks, or the supporting area of a reclining person
- vibrations applied to particular parts of the body such as the head or limbs, by vibrating handles, pedals or head-rests, or by the wide variety of powered tools and appliances held in the hand
- vibrations of specific interest in the occupational environment are normally classified as either:
  - whole body vibration, in the range of 1 to 80 Hz, or
  - segmental vibration, for example hand-arm, in the range of 8 Hz to 1 kHz.

Because the body acts as a mechanical system, it is subject to resonance in its various parts at various frequencies. When vibration occurs at or near any of these resonant frequencies the effect is greatly increased. The smaller the body member, the faster it can move and vibrate and so the higher the resonant frequency will be. For example, the head and shoulders resonate at a frequency of about 5 to 25 Hz, and the eyeball resonates in the range of about 30 to 80 Hz. This is illustrated in Figure 10.31, which shows a simplified model of the human body.

There are a number of physiological and psychological responses to vibration exposure.

10.14.1.1 Whole body vibration

Research has shown that the human body is most sensitive to vertical vibrations in the 4–10 Hz range. Studies by Kroemer and Grandjean (1997) show that vibrations between 2.5 and 5 Hz generate strong resonance in the vertebrae of the neck and the lumbar region. Vibrations between 4 and 6 Hz cause resonances in the trunk, shoulders and neck, and vibrations between 20 and 30 Hz set up the strongest resonances between the head and shoulders of seated persons. Other health effects and the associated frequency ranges include:

- motion sickness in the range 0.2–0.7 Hz, with the greatest effect at 0.3 Hz
- faults in the vestibular system of the ear caused by disturbance to the inner ear balancing system
- visual impairment affecting the efficiency of drivers of tractors, trucks, etcetera, in the range 10–30 Hz, and increasing the risk of accidents

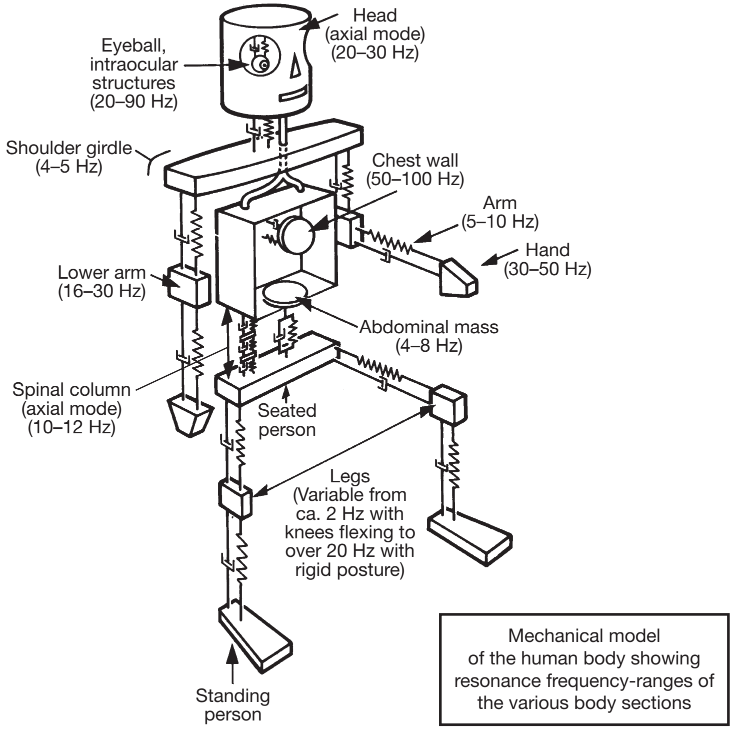

Figure 10.31 Frequency response ranges of different parts of the body
Source: Brüel & Kjær (1989)

- damage to bones and joints at frequencies below 40 Hz, especially the lower spinal region, for example ischaemic lumbago
- problems in the digestive system
- variations in blood pressure which may lead to heart problems
- disorders of menstruation, internal inflammation and abnormal childbirth in women exposed to 40–45 Hz vibrations
- increase in foetal heart rate when vibration (120 Hz) is applied to the mother's abdomen
- fatigue, loss of appetite, irritability, headache
- general reduced efficiency, which may lead to errors and/or accidents.

10.14.1.2 Hand-arm vibration

Segmental vibration affects a part of the body or an organ. The most prominent type of segmental vibration is hand-arm vibration, mainly experienced by operators of handheld power tools such as jackhammers, pneumatically-driven tools and chain-saws, etcetera.

Vibrations caused by these types of tools are usually found in the higher frequencies, such as 40–300 Hz. In this range vibrations may have ill effects on the blood vessels and nerve endings and blood circulation in the hands, causing:

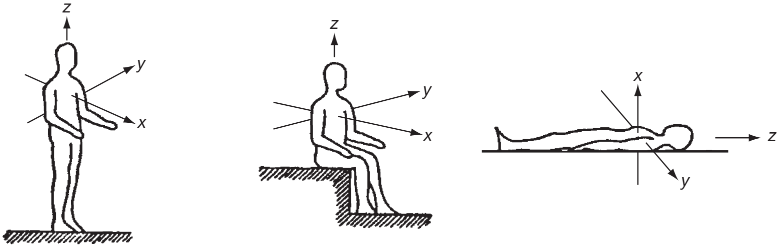

Figure 10.32 Whole body orthogonal coordinate system
Source: AS 2670.1—1990

- Raynaud's syndrome or vibration white finger (VWF) or dead finger syndrome. Initially the whitening (blanching) of the fingers is localised to the tips of the fingers most exposed to the vibrating source, but with continued exposure it spreads to involve all fingers and the tips of the thumbs
- nerve and blood vessel degeneration resulting in loss of senses of touch and heat and loss of grip strength
- pain and cold sensations between attacks of white fingers
- muscle atrophy, tenosynovitis
- damage to joints and muscles in wrists and/or elbows
- decalcification of the carpal tunnel
- bone cysts in fingers and wrists.

The symptoms and effects of VWF are aggravated when the hands are exposed to cold and/or the operator is a smoker.

The first symptoms are relatively mild (e.g. a tingling sensation in fingertips) and tend to disappear with cessation of exposure. With continued exposure, however, symptoms become progressively more severe and reach a stage where they become essentially irreversible—thus prevention is a high priority.

10.14.2 EXPOSURE GUIDELINES

The H&S practitioner will not find limits for vibration exposure under OH&S legislation. Nor do the Australian Standards® for whole body and hand-arm vibration specify limits for exposure. They do, however, provide information and guidelines on exposure level and duration. Although a dose-response relationship for vibration has yet to be developed, this does not mean that vibration exposure does not have to be limited. The general requirement to ensure health and safety at work applies and can most likely be achieved by demonstrating that proper diligence was applied for the particular situation. Proper diligence basically means taking care. An effective way of exercising proper diligence is through preparing a documented health and safety program, putting it into practice and regularly reviewing its effectiveness. Incorporated in such a program should be risk assessment and use of the relevant Australian Standards®.

The Standards applicable to vibration are:

- AS 2670.1 *Evaluation of Human Exposure to Whole Body Vibration, Part 1: General Requirements* (Standards Australia 2001)
- AS 2763 *Vibration and Shock—Hand-Transmitted Vibration—Guidelines for Measurement and Assessment of Human Exposure* (Standards Australia 1988).

Standards for vibration in the workplace are expressed in terms of **acceleration** (ms^2) and **duration of exposure** and take into account the frequency of the vibration.

10.14.3 VIBRATION MEASUREMENT

Measuring whole body or segmental vibration is rarely a task for the H&S practitioner, and the services of an expert with appropriate equipment will usually be required.

The vibration has to be measured in the three planes, that is, Z (up-down), X (back-forward) and Y (side-to-side), and for this purpose a triaxial accelerometer is normally used. One plane of vibration is usually dominant.

Common types of transducers fit onto the seat of a vehicle (whole body) or onto the back of the hand (segmental) as shown in Figure 10.33.

Figure 10.33 Measurement of whole body and hand-arm vibration
Source: Brüel & Kjær (1989)

10.14.3.1 Measurement of whole body vibration

ISO Standard 2631.1 (ISO 1997) and AS 2670.1 (Standards Australia 2001) indicate three criteria for the assessment of whole body vibration in different situations in the workplace. These are:

- the effects on human health and comfort
- the probability of vibration perception
- the incidence of motion sickness.

The Standard does not specify or recommend limits of exposure but the annexes provide information on the possible effects on health, comfort and perception.

Annex B is the important one for the assessment of whole body vibration with respect to human health. It applies to rectilinear vibration along the X, Y and Z axes of the human body, for people in normal health who are regularly exposed to vibration.

Figure 10.34 shows the health guidance caution zones for whole body vibration. For the assessment of effects on health, two relationships can be used, that is, the average acceleration value (equation B1) and the vibration dose value (equation B2). Exposures below the zones constitute an unlikely health risk as health effects have not been clearly demonstrated. For the zones between the dotted lines, caution is indicated with respect to potential health risks, and with exposure above the zones health risks are likely. These recommendations are, according to AS 2670.1, mainly based on exposures of 4–8 hours.

The caution zone should be viewed as an 'action level' where intervention to control the exposure is necessary. Exposures in the 'likely health risk zone' would be considered unacceptable under OH&S legislation.

For vibration taking place in more than one direction simultaneously, as is typically the case with whole body vibration, AS 2670.1 *Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole Body Vibration, Part 1: General Requirements* (Standards Australia 2001), suggests the effects of such vibration can be calculated by taking the vector sum, **a**, of the three weighted acceleration values, $\mathbf{a}_x$ and $\mathbf{a}_y$ and $\mathbf{a}_z$, as follows:

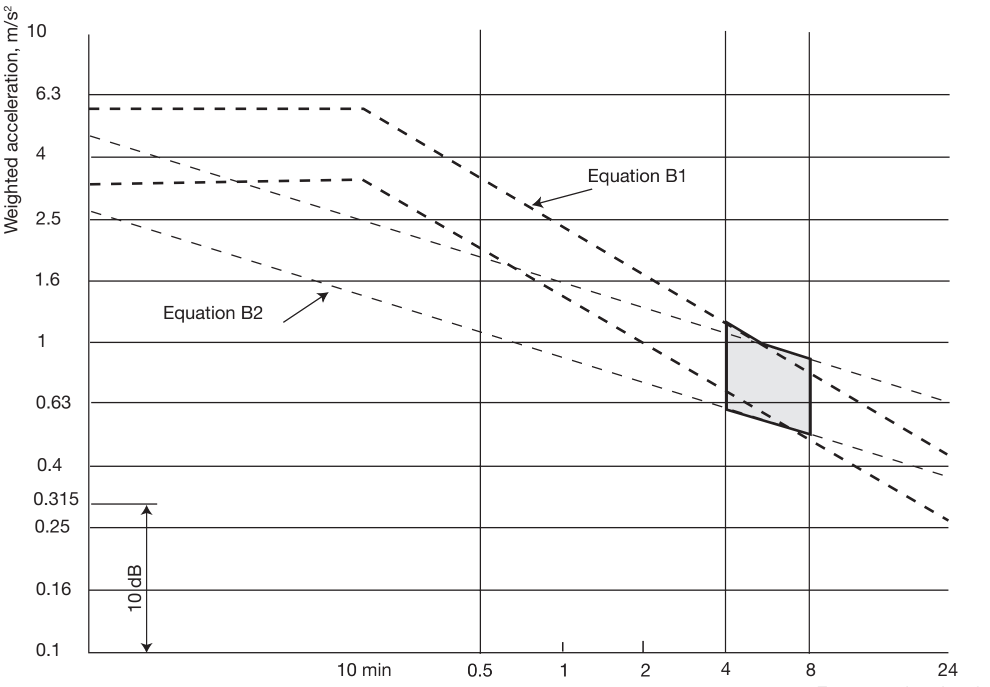

Figure 10.34 Health guidance caution zones
Source: Standards Australia (2001)

$$a = \sqrt{[\,(1{,}4\,a_x)^2 + (1{,}4\,a_y)^2 + a_z^2\,]} \qquad \text{(Equation 10.5)}$$

The actual exposure time, expressed as a percentage of the total allowed exposure time, is known as the equivalent exposure percentage.

10.14.3.2 Measurement of hand-arm vibration

ISO Standard 5349 (ISO 1986) and AS 2763 (Standards Australia 1988) do not provide limits for safe exposure to hand-arm vibration but they do provide guidelines for its assessment. These Standards suggest that the directions of vibrations be measured and reported using two orthogonal coordinate systems. These are the basicentre system and the biodynamic system. The basicentre system refers to the tool and the biodynamic system refers to the hand.

ISO 5349 (1986) and AS 2763 (Standards Australia 1988) provide a chart allowing predictions to be made for when the first signs of VWF in workers will occur depending on exposure levels and duration. An example from this chart is shown in Figure 10.35.

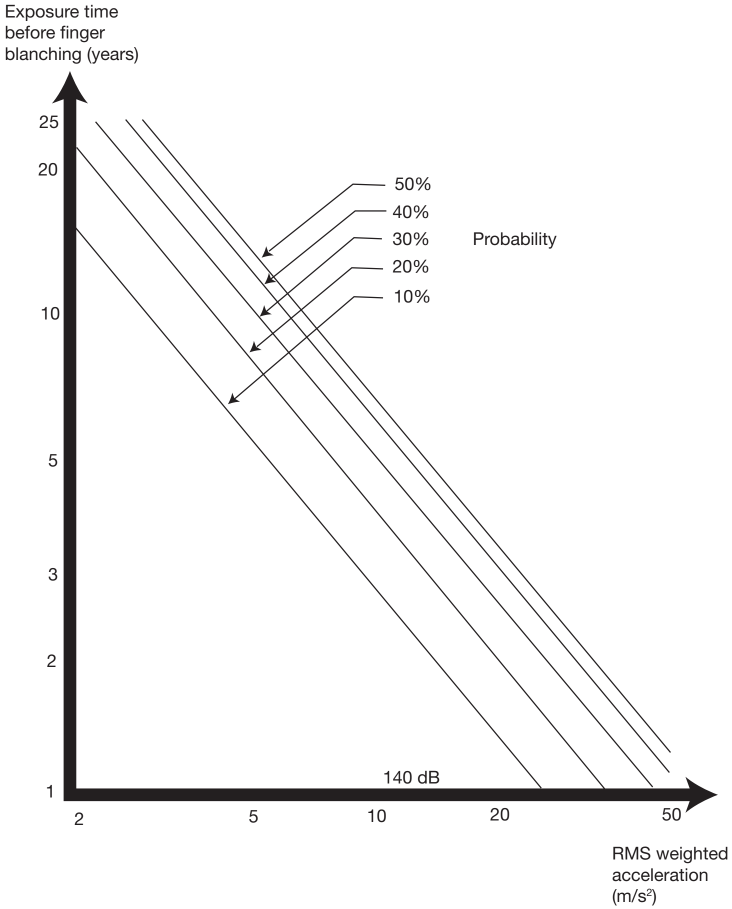

Figure 10.35 Exposure time of percentiles of population groups exposed to vibration suffering mild effects on tip of finger

Source: Brüel & Kjær (1989)

The probability lines of Figure 10.35 can be used to assess the long-term effects of 4-hour/day exposures to hand-arm vibration. For example, the 50 per cent line predicts that exposure to 20 m/s^2 vibration acceleration will cause 50 per cent of exposed workers to reach stage 1 of VWF (blanching and tingling sensation in fingertips which tends to disappear with cessation of exposure) due to occupational origins in about 3 to 4 years. At a vibration acceleration of 5 m/s^2 it would take about 15 years for the same percentage of workers to reach stage 1.

The data on which the chart is based is, however, limited and cannot be used for exposures greater than 50 m/s^2 or exceeding 25 years.

If the vibration acceleration is measured over a period other than 4 hours, then the equivalent acceleration period can be calculated using the following equation:

$$a_{\text{(h.w.) eq (4)}} = (T/_{T4})^{1/2} \, (a_{\text{(h,w) eq (T)}}) \qquad \text{(Equation 10.6)}$$

where:

$a_{\text{(h.w.) eq (T)}}$ = frequency weighted energy equivalent acceleration for period T
T = period of measurement in hours
T_4 = 4 hours.

If the operation is such that the total daily exposure is made up from several exposures at different frequency weighted accelerations, then the total frequency weighted acceleration may be calculated using the equation:

$$(a_{\text{(h.w) eq (T)}} = [I/T \;\; \{a_{\text{(h.w) eq (ti)}\}}{}^{2} T_i]^{1/2} \qquad \text{(Equation 10.7)}$$

where:

T = total duration of all exposures
$a_{\text{(h.w) eq (T)}}$ = frequency weighted energy equivalent acceleration for the i_{th} exposure component of duration t_i.

10.14.3.3 Motion sickness

One other kind of vibration, which can lead to the special problem of motion sickness, is vibration in the frequency range of 0.1 to 0.63 Hz in the vertical Z axis. In this range, a significant proportion of unadapted persons will experience discomfort, depending on frequency and exposure times.

10.14.4 CONTROL MEASURES

Control of vibration is most important. It usually requires a combination of appropriate tool selection, good work practices and education programs, as well as medical surveillance. It also requires identification of the hazards through vibration measurements and reduction at the source or transmission. Where vibration is a problem, workers should be warned of the hazards of vibrating tools, and medical supervision should be employed to identify those workers showing the early signs of undue health effects or reversible VWF.

Some control measures for whole body vibration include:

- insulation of seat and head rest vibration through springs and dampers
- installation of vibration dampening seats (suspension seats) that allow correct adjustment for the handling of the vehicle and do not interfere with visibility from the cab
- implementing a seat maintenance system to ensure suspension seats are regularly checked and maintained in a serviceable condition
- ensuring that only vehicles suitable for the job, including driver comfort, are used
- ensuring that cab layouts are such that drivers do not have to adopt awkward and potentially damaging postures
- ensuring that all on-site road and work area surfaces are well maintained to minimise rough rides
- ensuring that a traffic management system, that incorporates speed limits, operates on site
- ensuring that drivers of vehicles are familiar with the on-site road conditions
- ensuring that regular mini-breaks are incorporated in the shifts
- where required, and practicable, the provision of special boots with vibration-absorbing soles to protect against vibration through the floor
- limiting the time spent by workers on vibrating surfaces
- ensuring that plant and equipment are well maintained
- mounting of machines and plant on vibration isolating mounting pads.

Some control measures for hand-arm vibration include:

- isolating the vibrations, for example using special mountings and/or adjusting the centre of gravity as low as possible
- damping of the vibrations, for example wearing padded gloves, provided that this does not lead to an increase in clamping force, as increased clamping force results in increased transmission of vibrations.

The adverse effects can also be minimised if the operator's hands are kept warm or the handles of the vibrating tools are warmed in cold work situations.

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11. Ionising and non-ionising radiation

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11.1 INTRODUCTION

Radiation is energy in transit that can be in the form of either electromagnetic waves or high speed particles. Radiation in the form of electromagnetic energy is best understood by examining the electromagnetic spectrum shown in Figure 11.1.

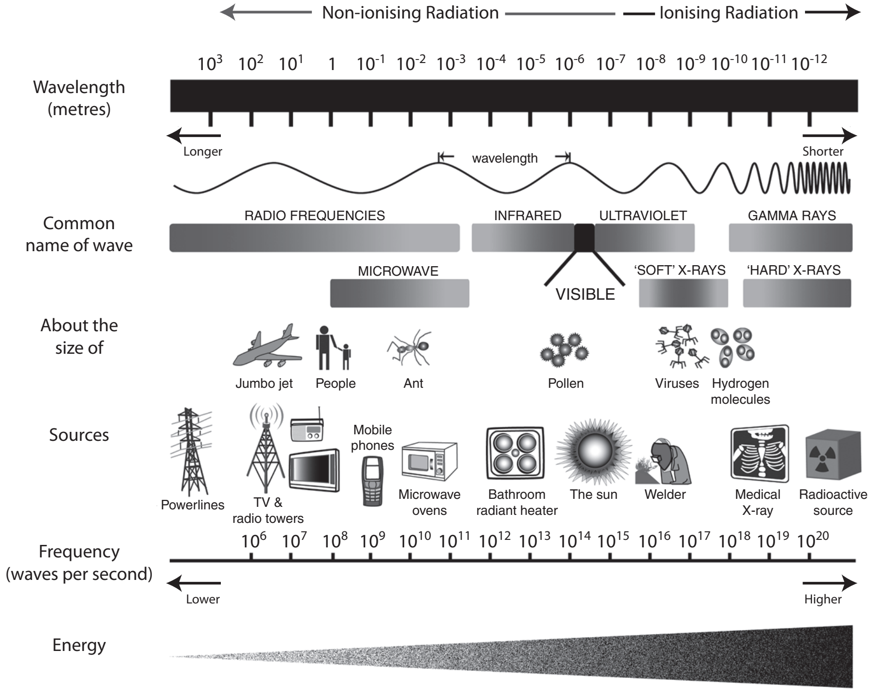

Figure 11.1 The electromagnetic spectrum (Note: diagram adapted from an electromagnetic spectrum by ARPANSA <www.arpansa.gov.au>)

In broad terms, the electromagnetic spectrum can be divided into radiations with sufficient energy to ionise matter ('ionising') and radiations without sufficient energy to ionise ('non-ionising').

All electromagnetic energy is characterised by its speed in a vacuum (the speed of light, c) of 3×10^8 m/s. Different radiations within the electromagnetic spectrum are described in terms of their wavelength (λ) in metres and frequency (f) in cycles per second or hertz (Hz). Wavelength and frequency are inversely proportional as shown in Equation 11.1.

$$f = \frac{c}{\lambda} \qquad \text{(Equation 11.1)}$$

X-rays and gamma rays are the highest energy electromagnetic ionising radiations. There are also particulate forms of ionising radiation, which behave differently to electromagnetic radiation. These are alpha, beta and neutron radiations. All ionising radiation is formed from the radioactive decay of unstable atoms. Figure 11.2 shows the different types of ionising radiation.

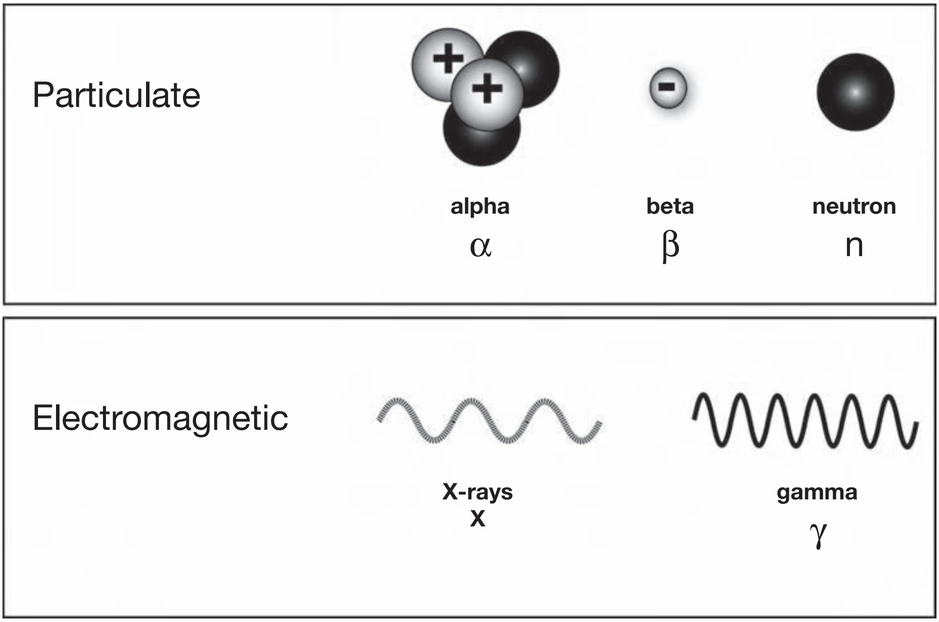

Figure 11.2 Types of ionising radiation

Ionising radiation has many practical uses, such as sealed sources and X-rays in medical and industrial applications, and unsealed sources in medical and research applications. There is a range of possible health effects associated with their use, such as cancer and effects on the skin, eyes, reproductive system and the unborn child.

The first part of this chapter examines ionising radiation by starting with its properties and then identifying common sources. Quantities used to measure ionising radiation are examined, followed by consideration of methods and instruments used for measurement. Finally health effects, exposure standards and control methods are considered.

Ultraviolet, visible, infrared, radiofrequency, extremely low frequency radiations, and static electric and magnetic fields are the main groups of electromagnetic non-ionising radiations. Lasers are a special application of visible, infrared and ultraviolet radiations. The latter part of this chapter examines each of these in terms of properties, sources, quantification, health effects and control methods.

The role of the H&S practitioner is considered for both ionising and non-ionising radiation. Both measurement and prescribing control measures for radiation are areas that often call for specialist expertise. In either case, a health physicist or an occupational hygienist who specialises in the area of radiation should be able to assist. Health physicists are usually members of the Australasian Radiation Protection Society (ARPS) or the Australian College of Physical Scientists and Engineers in Medicine (ACPSEM), and occupational hygienists may be sourced through the Australian Institute of Occupational Hygienists (AIOH). The Australian Nuclear Science and Technology Organisation (ANSTO) and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) both employ many experts in radiation. They also provide useful information on their websites.

A: IONISING RADIATION

11.2 PROPERTIES

11.2.1 INTERACTION WITH MATTER

As they travel through matter, alpha (positive charge) and beta (negative charge) particles use their charge to knock electrons off the target atoms that they come into close contact with, creating positive and negative ions, in a process known as 'ionisation'.

Gamma rays and X-rays cannot directly ionise other atoms as neither type has any charge. However, their electric and magnetic fields can interact with atoms by imparting their energy to the electrons and thus causing ionisation in the target atom.

Neutrons also have no charge and thus cannot directly ionise target atoms. Instead, they cause ionisation indirectly by interacting with the forces inside the nucleus of the target atom. In this process, neutrons can cause stable materials to become radioactive and to remain this way after the neutron source has been removed. Neutrons are the only type of ionising radiation that can do this.

11.2.2 PENETRATING VERSUS IONISING ABILITY

The ability of ionising radiation to penetrate through matter and cause ionisation is an integral part of its hazard. This section reviews the penetrating and ionising ability of the different types of ionising radiation, as they vary considerably.

Alpha particles consist of two protons and two neutrons (that is, a helium nucleus). They are heavy, slow-moving and have two positive charges. Their large mass and charge means that alpha particles interact easily with matter through which they pass and cause a lot of ionisation over a short distance. Alpha particles usually travel only a few centimetres in air before their energy is reduced by interacting with target atoms and acquiring two electrons to form a stable helium atom.

Beta particles are fast-moving electrons of very low mass, which originate from the nucleus. Beta particles have less charge and much less mass than alpha particles and as a result cause less ionisation over the same travel distance than alpha particles. However, beta particles pass through a longer path before relinquishing all of their energy and eventually being taken up by atoms seeking free electrons. Beta particles typically travel up to 3 metres in air, but travel distance varies according to their energy. Phosphorus-32 is a high energy beta emitter and the beta particles may travel up to 7 metres in air. Low energy beta radiation such as that from tritium (hydrogen-3) travels less distance in air than most alpha particles.

Neutrons have varying ionising capability, although they have no charge. Depending on their energy, they may be more or less ionising than alpha and beta particles, gamma rays or X-rays. Their range of energies often means that neutrons will travel many metres in air before stopping completely.

As a general rule, X-rays and gamma rays are the least ionising of all types of ionising radiations. Depending on their energy, they also will travel very large distances through matter until all their energy is expended by interactions with target atoms.

This means that they generally travel further through matter than either alpha or beta particles. Like neutrons they typically travel many metres.

Penetrating and ionising abilities for all types of ionising radiation are summarised in Figure 11.3. It is important to have some knowledge of penetrating and ionising properties of the different types of ionising radiation, as these properties impact on the biological effects and the exposure control methods that will be used.

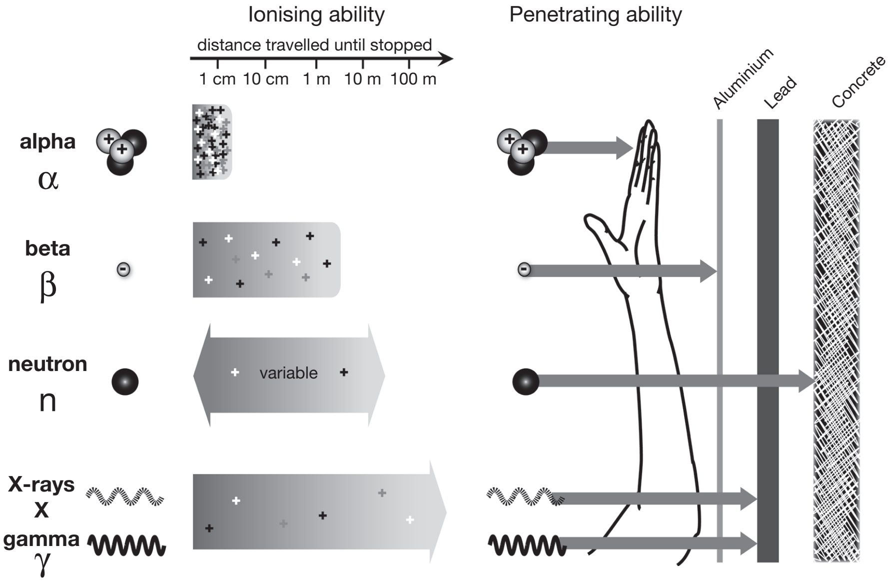

Figure 11.3 Penetrating and ionising ability

11.2.3 INTERNAL AND EXTERNAL RADIATION HAZARD

The hazard presented by ionising radiation can be internal and/or external, depending on whether the radioactive material has the potential to enter the body. It is important to remember that radioactive material can still present a hazard when it is outside the body.

The external radiation hazard occurs when a source of ionising radiation is outside the body. The danger lies in the fact that a person may be irradiated without being aware of it, and without coming into contact with the source. The greatest external radiation hazard is posed by X-rays, gamma rays and neutrons because of their ability to travel large distances and penetrate the human body. Even if they are close to the body, alpha particles and some beta particles (e.g. those from tritium) do not represent a significant external radiation hazard as they are unable to penetrate the outer layer of skin. Beta particles that are more energetic and penetrating do present an external hazard. For example, phosphorus-32 (a beta emitter) may cause skin burns when exposure is uncontrolled.

Alpha and beta radiation represent the greatest internal radiation hazard once they are inside the body as they are capable of causing intense ionisation in a local area. X-rays, gamma rays and neutrons, on the other hand, will cause some local ionisation, but a large proportion of the radiation is likely to pass out of the body altogether.

Radioisotopes can enter the body to cause an internal radiation hazard by three different means:

- **Ingestion** is the most common means and occurs by putting contaminated items in the mouth.
- **Inhalation** of radioactive vapours or aerosols such as mist from a centrifuge. Unbound radioactive iodine is a particular danger due to the volatility of this material.
- **Via intact skin** or **through wounds**. Radioactive materials will permeate even intact skin if the contact time is long enough, and particularly if they are mixed with another substance that readily penetrates the skin such as an organic solvent. Where there is a wound, radioactive materials can permeate even more readily.

11.3 SOURCES

11.3.1 OVERVIEW

Background exposure to ionising radiation can come from natural or man-made sources. Sources of exposure to ionising radiation can also be grouped as being of either medical or work-related origin. Exposure standards for ionising radiation are discussed in Section 11.7.

11.3.2 BACKGROUND EXPOSURE FROM NATURAL SOURCES

We are all exposed to significant amounts of background ionising radiation just by living on planet Earth. Cosmic radiation comes from the sun and its intensity varies with altitude. This results in aircrew having a significantly higher background radiation dose than members of the public. Other background exposure comes from a range of naturally occurring radioisotopes such as potassium-40 (gamma emitter), uranium-238 (alpha emitter) and thorium-232 (alpha emitter), which are found in the soil, air and water and consequently in the food that people eat.

Naturally occurring radioactive material (NORM) may be found in materials that are mined, such as minerals, oil and gas. Although the concentrations of radioactive material may be low in the naturally occurring materials, the refinement processes often concentrate the mined material, leading to process lines or waste that contain levels of radioactivity higher than background. Examples include thorium-232 and uranium-238 in mineral sands mining and processing, and radium-226 (and associated radon daughters) in oil and gas production (Cooper 2005).

The naturally occurring radioisotope radon-222 (alpha emitter) has caused concern overseas, where it is often concentrated in building materials and may accumulate inside buildings that are not well ventilated. In Australia, the Buchan Caves in Victoria are an example of an enclosed area where levels of radon may be high. Radon levels are generally lower in Australia than many other countries due to the local geology and types of soils and rocks.

Another Australian example of elevated levels of naturally occurring radioisotopes is seen in the Darling Scarp in Western Australia. It has rocks that are particularly rich in uranium-235 (alpha emitter) and thorium-232, which results in a higher than average background radiation dose for persons living in that area.

11.3.3 BACKGROUND EXPOSURE FROM MAN-MADE SOURCES

In addition to natural sources of background radiation, man-made nuclear events such as the Chernobyl accident in Ukraine, and the bombing of Hiroshima and Nagasaki in Japan, have added to the background radiation exposure for all persons on the planet. Nevertheless, the additional background exposure to ionising radiation from these sources is insignificant in countries like Australia which are a long way from the sites of these incidents.

Nuclear testing was undertaken in parts of Western and South Australia in the 1950s, but the background level of radiation to Australians was estimated to have risen by only a few microsieverts in the years immediately following these tests (Wise & Moroney 1992). Other countries such as France undertook nuclear testing in the Pacific region during the 1990s, and made a minimal contribution to the background radiation level.

11.3.4 MEDICAL EXPOSURE

Medical exposure is another source of ionising radiation dose encountered by all persons who undergo diagnostic or treatment procedures using ionising radiation. X-ray machines are used for medical imaging of parts of the body and for treating cancers. Some radioisotopes are given to patients by mouth, or are injected for diagnostic or treatment procedures. An example is the injection of technicium-99m (gamma emitter; 'm' means metastable, a physical characteristic of this radioisotope), for brain scans or iodine-131 (gamma emitter) for thyroid scans. Radioisotopes may also be used for treating cancer. For example, cobalt-60 (gamma emitter) is used externally, directed at the site of an internal tumour, or a small iodine source is implanted in the tongue to treat tongue cancer.

11.3.5 WORK-RELATED EXPOSURE

In addition to background and medical sources of ionising radiation, a small proportion of our community is required to work with sources of ionising radiation. Work-related doses vary depending on the work. Table 11.1 shows a comparison of work-related annual doses for workers in various occupations in Australia (Morris et al. 2004). These should be compared with annual external dose limits given in Section 11.7.1, and with the annual average dose from background radiation in Australia (excluding medical and work-related sources) of approximately 2 μSv/year.

Table 11.1 Typical work-related radiation doses for workers in various occupations in Australia in 2004

Occupation	Average whole body dose (µSv/year)
Radiologists in large hospitals	108
Dentists in private practice	12
Uranium miners	1125
Students in research and education	19

Source: Derived from Morris et al. (2004)

11.3.6 FORMS OF MAN-MADE SOURCES

It is useful to further classify sources encountered within the workplace based on their form, because these forms influence the type of the hazard presented by the ionising radiation. There are three forms of man-made ionising radiation:

- irradiating apparatus
- sealed sources and sealed source apparatus
- unsealed sources.

Irradiating apparatus refers to equipment that generates ionising radiation, for example, X-ray machines, cyclotrons and neutron generators.

A sealed source, or sealed source apparatus, is any quantity of radioisotope whose physical form is so enclosed as to prevent the escape of any of the radioisotope (but not the radiation itself). Some examples are:

- nickel-63 is used as a beta source within an electron capture detector in gas chromatographs
- level and thickness gauges use a variety of radioactive sources such as americium-241 (alpha emitter), caesium-137 (gamma emitter) and cobalt-60 (gamma emitter).

Bore-hole loggers employ an americium-241 source to cause fission (producing neutrons) in beryllium. In the measurement of moisture, the resulting fast neutrons are directed at materials for measurement; if water is present, they are slowed by the hydrogen atoms in the water. The resulting slow neutrons can be detected using a proportional counter and thus moisture content is measured.

Unsealed sources are usually in liquid or powder form and may readily escape into the environment if they are not carefully contained. They are most often used for scientific research in applications such as:

- iodine-125 (gamma emitter) for labelling peptides
- sulphur-35 (beta emitter), hydrogen-3 (tritium, beta emitter) and carbon-14 (beta emitter) for labelling steroids.

11.4 QUANTIFICATION

11.4.1 OVERVIEW

In order to understand how we quantify ionising radiation we need to introduce several different quantities:

- activity
- half-life
- energy
- exposure
- dose.

11.4.2 ACTIVITY

Activity describes the amount of radioactivity present. The international standard (SI) unit for activity is the becquerel (Bq). One Bq is equivalent to one disintegration per second. The imperial unit of activity is the curie (Ci). The relationship between the becquerel and the curie is shown in Equation 11.2.

$$1\ Ci = 3.7 \times 10^{10}\ Bq \qquad \text{(Equation 11.2)}$$

11.4.3 HALF-LIFE

The process of radioactive decay is an exponential one, whereby the activity of a set amount of radioactive material decreases with time. This pattern of exponential decay can be used to predict how long that decay might take, as shown in Figure 11.4.

The radiological half-life ($T_{1/2}$) is the time taken for half a group of atoms to undergo radioactive decay. The relationship between activity and radiological half-life is defined by equations 11.3 and 11.4.

$$A_t = \frac{A_0}{2^n} \qquad \text{(Equation 11.3)}$$

where:

A_t = activity at time elapsed (t)
A_0 = the original activity at $t = 0$
n = the number of half-lives

$$n = \frac{t}{T_{1/2}} \qquad \text{(Equation 11.4)}$$

where:

t = time elapsed
$T_{1/2}$ = radiological half-life

The biological half-life of a radioisotope is a similar concept, and measures the time taken for half a set amount of radioactivity to be eliminated from the body.

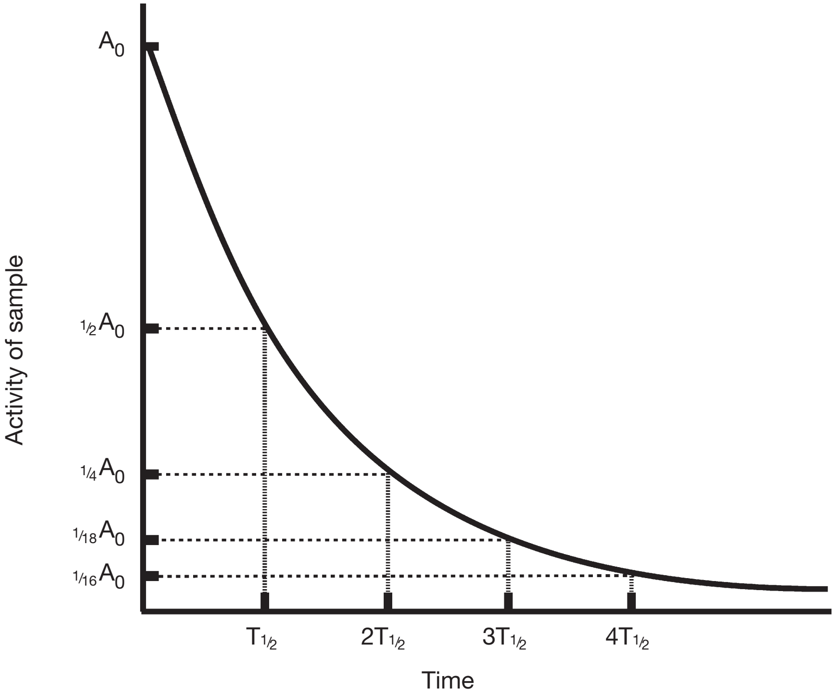

Figure 11.4 The pattern of radioactive decay

11.4.4 ENERGY

The SI unit for energy is the electron-volt (eV). All forms of ionising radiation sources have either a specific energy, or a spectrum of energies. The amount of energy affects the relative penetrating and ionising ability of each ionising radiation type. Typical energies for some ionising radiations are shown in Table 11.2.

11.4.5 EXPOSURE

Exposure is used to describe the amount of ionising radiation that could impact upon the body. Historically exposure was defined as the amount of ionisation that X or gamma rays produced on passing through air. This was measured in roentgens (R) and the SI unit is coulomb per kilogram (C/kg).

11.4.6 ABSORBED DOSE

Absorbed dose (*D*) is a measure of the energy absorbed per unit mass of absorbing material (the greater the density of the absorbing material, the greater the absorbed dose for a set type of ionising radiation of defined energy). The SI unit is joule per kilogram (J/kg) or gray (Gy). Dose is always less than exposure.

Table 11.2 Energies of ionising radiation

Type of radiation	Energy range
Alpha	4–9 MeV
Beta	Each radioisotope emits beta radiations with a spectrum of energies. The most probable energy is approximately one-third of the maximum energy. Average beta energies usually range between 1 keV and 5 MeV.
Gamma	One or more rays of characteristic energy. These are usually between 1 keV and 10 MeV.
X-rays	X-rays generated from X-ray machines have a continuous energy spectrum which depends on the energy of the beta radiation and the density of the target material in which they are generated. The average energy is calculated from the accelerating voltage of the X-ray machine.
Neutrons	Neutrons are referred to as either: • 'Fast' (energy > 0.1 MeV) • 'Slow' or 'thermal' (energy ≤ 0.1 MeV) All neutrons start out as fast neutrons, but their interactions with matter mean that ultimately they become slow or thermal neutrons before being completely stopped.

11.4.7 RADIATION WEIGHTING FACTOR AND EQUIVALENT DOSE

The amount of ionisation is important when considering the effect of ionising radiation on the body. In order to take account of differing ionising abilities between types of ionising radiation, the radiation weighting factor (ω_R) is used in the calculation of equivalent dose (H_T), according to Equation 11.5.

$$H_T = \Sigma(\omega_R \times D) \qquad \text{(Equation 11.5)}$$

The equivalent dose is used to quantify the dose received by an individual from various types of ionising radiation. Doses to extremities are reported as equivalent dose. Equivalent dose has units of sievert (Sv). Radiation weighting factors represent the relative amount of damage likely to be caused to living cells by different types of radiation and are listed in Table 11.3.

11.4.8 TISSUE WEIGHTING FACTOR AND EFFECTIVE DOSE

Some tissues are more sensitive to the effects of ionising radiation than others. Tissue weighting factors (ω_T) are used to take account of the differing sensitivities of various organ systems in the body to ionising radiation and are used in the calculation of effective dose (E) using Equation 11.6.

Table 11.3 Radiation weighting factors

Radiation type	Radiation weighting factor
Alpha	20
Beta	1
Gamma and X-rays	1
Neutrons	5–20 depending on energy

Source: ICRP (2004)

$$E = \Sigma\ (H_T \times \omega_T) \qquad \text{(Equation 11.6)}$$

The effective dose is used to quantify the annual whole body dose (usually reported as cumulative dose) received by an individual. Effective dose has units of sievert (Sv). Tissue weighting factors represent the relative amount of damage likely to be caused to different organ systems in the body and are listed in Table 11.4.

Table 11.4 Tissue weighting factors

Organ system	Tissue weighting factor
Bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.12
Bladder	0.05
Gonads	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Brain	0.01
Kidneys	0.01
Salivary glands	0.01
Bone surface	0.01
Remainder (including: adipose tissue, adrenals, connective tissue, extrathoracic airways, gall bladder, heart wall, lymphatic nodes, muscle, pancreas, prostate, SI wall, spleen, thymus and uterus/cervix)	0.10

Source: ICRP (2004)

The following example shows how equivalent dose and effective dose are calculated.

Calculate the equivalent dose of 30 μGy of alpha radiation to the bladder and 2.5 mGy of gamma to the lungs:

$$H_T = (20 \times 30) + (1 \times 2500) = 600 + 2500 = 3.1\ mSv$$

Calculate the effective dose for the same situation:

$$E = (0.05 \times 600) + (0.12 \times 2500) = 30 + 300 = 330\ \mu Sv$$

11.5 MEASUREMENT

11.5.1 TYPES OF INSTRUMENTS

There are three types of instruments for measuring ionising radiation:

- count rate meters
- dose rate meters
- dosimeters.

Each of these instruments, which measure different quantities, is commonly available in workplaces where ionising radiation is used. Some examples are shown in Figure 11.5.

Figure 11.5 Instruments for measuring ionising radiation

11.5.2 CHOICE OF A MONITORING INSTRUMENT

No single instrument has universal application to all types and all energies of radiation. There are also varying sensitivities between different instruments. Hence it is important to consider the type of radiation and the energy response curve for any detector in relation to the energy of the radiation that you wish to measure. Figure 11.6 shows some typical energy response curves for various types of detectors.

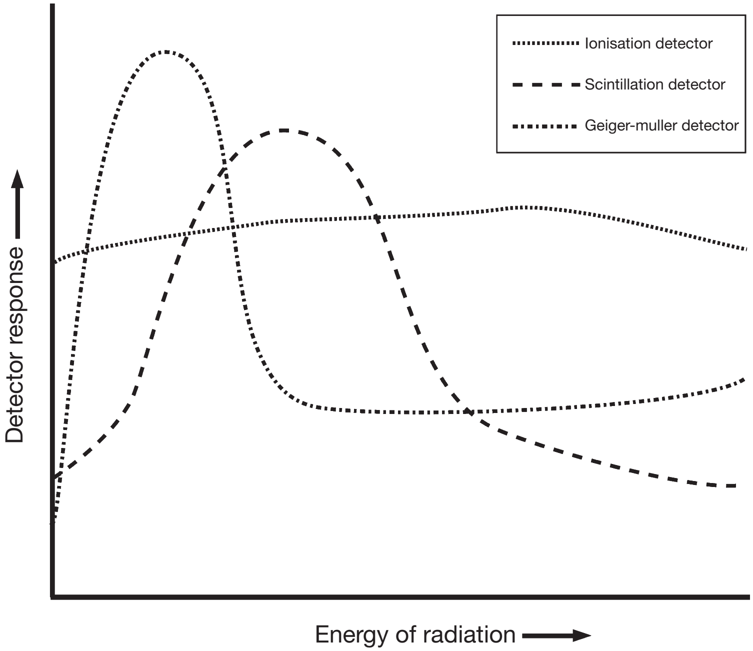

Figure 11.6 Energy response curves for several detectors

The **geiger muller detector** is most responsive at lower levels of energy, but only for a limited energy range. The **scintillation counter** has a lesser response, but to a wider range of radiation energies, and the type of radiation detected is highly dependent on the choice of scintillant material. Finally, the **ionisation chamber** has a fairly insensitive response to an even wider range of energies. It is important to know the type of radiation and the energy of the radiation to be measured to enable the choice of the most appropriate detector.

Sensitivity is also an important consideration. High sensitivity will be required for measuring low level contamination. This is usually achieved with a large surface area on the detector. However, if such an instrument is used for measuring high levels of contamination, then partial saturation of the detector may lead to a false low response. Using a large surface area detector when surveying for beams of radiation can also give false low readings, as the radiation detected is averaged over the entire volume of the detector. In the case of measuring pulsed X-ray fields, the response of a detector may be too slow unless the instrument has been specifically designed for this purpose.

11.5.3 CALIBRATION AND PERFORMANCE CHECKING

Performance checking should be undertaken every time a radiation measuring instrument is used. The battery should be checked for sufficient energy and the detector should be inspected for damage. The detector should be checked against a suitable source (preferably of the same radiation being monitored), and its response noted. This should be logged in a book and compared over time, to watch for any deterioration in detector performance.

Calibration is a more in-depth examination of the performance of the radiation monitor and requires the services of a specialist calibration service such as ARPANSA or ANSTO. This should be undertaken at regular intervals, and at any time that the radiation monitor has been repaired, knocked, damaged or otherwise altered.

11.5.4 MEASURING THE EXTERNAL RADIATION HAZARD

Dosimetry is the measurement of either whole body dose, or the dose to certain parts of the body. Whole body dose is assessed by using a single dosimeter such as a thermoluminescent detector (TLD), usually worn on the waist in order that the measurement is taken as near as possible to the gonads, which are very sensitive to radiation (see Table 11.4). At the end of the wearing period, the TLD badge is sent away for analysis. If a lead apron is worn, then the TLD should be positioned beneath it at the waist or chest position in order that it represents actual, rather than theoretical, dose. TLD badges and analytical services are available from ARPANSA, Queensland Health Scientific Services and several private companies.

TLD badges are commonly used to measure equivalent dose over periods of 8–12 weeks. They may be changed more frequently if the radiation worker is undertaking work where high doses of ionising radiation may be delivered, if there has been an incident where a high dose is suspected, or if the worker is pregnant. The measurements of equivalent dose are used to calculate effective dose (as in Section 11.4.8), usually over a single year for a particular radiation worker, and then compared with external exposure standards (Section 11.7.1).

Other whole body dosimeters that are readily available and are used for shorter duration measurement of whole body, external, equivalent dose of ionising radiation, are digital audio dosimeters (DAD) and quartz fibre dosimeters (QFD). These measure dose or dose rate and, with knowledge of the time involved in a task involving exposure to radiation, the results can be used to establish whether or not control methods are adequate.

Equivalent doses to parts of the body can be measured using small TLD badges. For example, finger monitoring can be done using a TLD that can be wrapped around the fingers to measure dose to the hands. The results of this monitoring can be compared against exposure standards for the skin and hands (see Section 11.7.1).

Area monitoring for ionising radiation must be undertaken in three dimensions because ionising radiation can diffract and scatter around corners. An instrument measuring count rate or dose rate is most commonly used. The area to be monitored should be mapped out on a grid pattern and measurements taken at each grid point. For the sake of personal safety and to avoid false readings from monitors that may have a slow response time (particularly after a high reading), the monitoring should be commenced from the farthest point in relation to the ionising radiation source. Using this method of monitoring, it is possible to quickly establish areas where no person should enter or where the time of exposure should be limited.

Surveying for contamination on surfaces should be undertaken before and after a procedure that uses unsealed sources of ionising radiation has been performed. It is often the only method of detecting and removing surface contamination that may be contacted by a worker and taken into the body by ingestion.

Wipe testing is a variation on monitoring for surface contamination. It is particularly useful when the ionising radiation type has very low energy, is very dilute on the surface or does not give a strong signal to a survey instrument, or when there is a high radiation background that may interfere with the survey instrument. An example where wipe testing may be used is checking the integrity of a sealed source or checking for contamination on surfaces in a radiation source storage area. A moistened filter paper is wiped across the surface believed to be contaminated. This concentrates any radioactive contamination on the filter paper. The filter paper can then be monitored using a survey instrument (usually a calibrated count rate meter), or counted using laboratory instrumentation such as a liquid scintillation counter.

Monitoring for airborne contamination should be undertaken where there is a risk of inhaling the radioisotope, such as a radioactive dust or radioactive iodine. Monitoring for airborne radioactive material requires specialist methods and equipment (see Section 11.9).

11.5.5 MEASURING THE INTERNAL RADIATION HAZARD

Monitoring the internal radiation hazard should be undertaken routinely whenever unsealed sources are handled. Personal external contamination is considered to be an internal radiation hazard because of the ease with which radiation may enter the body at any time and the fact that the dose that results from it will not be measured by dosimetry methods that measure external dose, such as TLD badges. Personal external contamination should be approached using the same survey instrument used to do area surveys for contamination (see Section 11.5.4). This is best done in pairs, with a clean person surveying a person who is potentially contaminated. The surfaces of laboratory coats, cuffs, hands and feet are the usual areas for personal external contamination.

Thyroid monitoring should be undertaken immediately prior to, and also approximately 4 hours after, any process using radioactive iodine where volatile iodine may be released. In this procedure, a very sensitive scintillation detector, calibrated and specifically set up for the purpose, is used to ascertain the amount of radioactive iodine that has entered the thyroid gland. Thyroid monitors are not common, but they are usually operated by facilities that use unsealed sources of radioactive iodine. ARPANSA or ANSTO would be a useful first point of contact in locating such an instrument.

Whole body monitoring is usually only done when someone suspects that they have taken a large dose of radioisotope internally. It is performed using a similar monitor to that used for thyroid monitoring and only detects gamma, X-ray and high energy beta radiation. There are only a few facilities in Australia that operate instruments for whole body monitoring. Again, ARPANSA or ANSTO would be a useful first point of contact in locating such an instrument.

Bioassay monitoring involves monitoring a biological tissue or body product such as urine, blood, faeces, hair or sweat for radioactive materials. The most common bioassay methods involve monitoring urine for radioisotopes such as tritium (beta emitter), sulphur-35 (beta emitter) and sometimes carbon-14 (beta emitter). Urine samples can be taken and counted, using an instrument such as a laboratory scintillation counter, before and after a procedure where the person has used these isotopes. The difference in the readings and the time elapsed after possible intake of the radioisotope allows an estimate of the dose.

11.6 HEALTH EFFECTS

11.6.1 WHOLE BODY EFFECTS

Whole body effects include radiation sickness, cancer and death. A short-term dose of approximately 1 Gy may result in radiation sickness (ICRP 1990a). This manifests as symptoms of nausea, vomiting, rapid pulse and fever within a few hours of the exposure. Doses of this magnitude are not common and historically have usually been associated with accidents.

Cancer may occur in virtually any organ of the body depending on the radioisotope, the dose and the type of radiation involved. Cancers known to be induced by exposure to ionising radiation include:

- leukaemia in atomic bomb survivors
- lung cancer in uranium miners due to inhaling radioactive dust
- bone sarcoma in workers who used radium-containing paint to decorate the faces of luminous clocks and dials. The workers pointed their brushes between their lips to get a fine point and ingested radium in the process.

Death due to a short-term dose of ionising radiation only occurs at very high doses. A short-term dose of 3–5 Gy results in damage to the bone marrow and death within a few months. Doses of 5–15 Gy cause damage to the gastrointestinal tract and lungs, and death within a few weeks. For short-term doses in excess of 15 Gy, damage to the central nervous system results and death occurs within a few days (ICRP 1990a). Experience of high short-term doses and the effects that result from them has typically been confined to accidents.

11.6.2 SKIN EFFECTS

Skin effects include hair removal, reddening of the skin, burns and cancer. Reddening and damage to the outer layer of skin occurs with short-term doses of around 3–5 Gy. The initial reddening lasts only a few hours, but may be followed several weeks later by a wave of deeper and more prolonged reddening (ICRP 1990a). Erythema is unlikely in modern workplace settings where ionising radiation is well controlled.

11.6.3 EFFECTS ON THE EYES

The lens of the eye is prone to the formation of cataracts as a result of ionising radiation breaking down the dividing cells in the epithelium of the lens, although this is unlikely where ionising radiation exposure is well controlled. Cataracts may be induced by single, relatively large short-term doses or by a series of smaller doses.

11.6.4 EFFECTS ON THE REPRODUCTIVE SYSTEM AND HEREDITARY EFFECTS

The effects of ionising radiation on the reproductive system are important for both sexes as the reproductive cells are highly radio-sensitive. Temporary or permanent sterility may be induced by short- or long-term doses in the region of the testes or the ovaries. Temporary male sterility may result from a one-off dose of 0.15 Sv. A one-off dose of 3.5–6 Sv may cause permanent male sterility. In the female, a one-off dose of 2.5–6 Sv may cause permanent sterility (ICRP 1990a). Doses of sufficient magnitude to cause sterility are unlikely in settings where exposure to ionising radiation is well controlled: also, they usually occur at higher doses than those where other health effects would be observed, such as radiation sickness.

However, it is not only the person irradiated who is of concern in relation to reproductive effects. Damage to the reproductive cells of either men or women may result in genetic disorders being passed to future generations. This is known as the hereditary effect of ionising radiation.

11.6.5 EFFECTS ON THE UNBORN CHILD

Radiation effects on the unborn child are of particular concern where radiation workers may be pregnant, because the foetus may be affected at doses which are lower than those required to cause any discernible effect in the mother. The effect that ionising radiation has on the unborn child depends entirely on the stage of development. A high short-term dose early in the pregnancy may result in the death of the foetus and a miscarriage. Any organ under formation at the time of exposure may be deformed by exposure to ionising radiation. Later on in the pregnancy, the IQ of the unborn child may be adversely affected by exposure to high doses of ionising radiation. Radiation exposure must be carefully controlled, even in the most modern facilities, in order to ensure no effects on the unborn child.

11.7 EXPOSURE STANDARDS

11.7.1 EXTERNAL DOSE LIMITS

Exposure standards that apply to external exposure to ionising radiation are commonly known as dose limits and are defined in Table 11.5. Dose limits for use in Australia are established by ARPANSA based on international recommendations and are adopted into legislation by each state or territory. Dose limits are defined for radiation workers as well as for members of the public. A radiation worker is a person who is exposed to ionising radiation as part of their work and the dose limits that apply to radiation workers are specifically for their work-related exposure, not for background or medical exposure to ionising radiation. Background and medical exposure to ionising radiation are not considered as part of the dose limitation for radiation workers or members of the public.

The group comprising members of the public encompasses all persons other than radiation workers, including the sick, the elderly and the very young. The tolerance of ionising radiation exposure for many members of the public would be less than that of a radiation worker. Hence the dose limits for members of the public are lower.

Table 11.5 External dose limits for ionising radiation

Application	Dose limit for a radiation worker	Dose limit for a member of the public
Effective dose	20 mSv per year averaged over a period of 5 consecutive years with no more than 50 mSv in any single year	1 mSv in a year A higher value is allowed in special circumstances as long as the average over 5 years does not exceed 1 mSv The limit for the unborn child is 2 mSv from the declaration of pregnancy on the basis that the abdomen provides shielding of 1 mSv (ICRP 1990b)
Annual equivalent dose:		
Lens of the eye	150 mSv	15 mSv
Skin (averaged over 1 cm^2 of skin)	500 mSv	500 mSv
Hands and feet	500 mSv	—

Source: ARPANSA (2002a)

11.7.2 INTERNAL DOSE LIMITS

Internal dose limits for ionising radiation are defined as allowable limits of intake (ALI) separately for inhalation and ingestion (ICRP 1991; Standards Australia 1998). The ALI is the limit of radioisotope which, when taken in by ingestion or inhalation, would irradiate the person to an effective dose equating to 20 mSv annually (i.e. the radiation worker whole body, external dose limit). For members of the public and for mothers of unborn children the ALI is reduced to 1/20th of that for a radiation worker. This is in line with the member of the public external dose limit of 1 mSv.

11.8 CONTROL METHODS

11.8.1 THE THREE TENETS OF IONISING RADIATION SAFETY

The philosophy behind safe management of ionising radiation is based on three tenets:

- **The justification of practice** This requires that no practice involving exposure to ionising radiation should be adopted unless the benefit outweighs the potential or actual harm. In practice this means that all persons who consider the use of ionising radiation in a procedure must consider the benefits that its use will bring and weigh these benefits against the risks.
- **The optimisation of protection** (the ALARA principle) This requires that the size of individual doses, the number of people exposed and the likelihood of incurring unplanned exposure is kept As Low As Reasonably Achievable (ALARA), with economic and social factors being taken into account.
- **Dose limitations** This requires that the exposure of individuals should be controlled according to recommended dose limits.

11.8.2 CONTROL METHODS FOR EXTERNAL RADIATION HAZARDS

Shielding is the most important control measure for reducing or eliminating exposure to the external radiation hazard. The selection of shielding materials and their placement around an isolated source of ionising radiation is a relatively easy task that may be undertaken by the H&S practitioner. However, in cases where a source has very high activity, or generates beams of ionising radiation, and there may be significant leakage through incorrect placement of shielding, specialist expertise should be consulted (see Section 11.1).

- **Alpha radiation** does not penetrate far and thus does not require a specific shield to protect against the external radiation hazard. It is usually possible to use distance for adequate protection. For instance, a pair of rubber gloves will provide adequate protection if an alpha source must be handled.
- **Beta radiation** is adequately shielded by a piece of aluminium several millimetres thick or a piece of perspex approximately 1 centimetre thick. It is not wise to use lead for shielding beta radiation as it increases the radiation hazard by producing

X-rays known as 'Bremsstrahlung radiation'. These are formed as a result of beta radiation being slowed quickly in a dense absorbing medium.
- **Gamma and X-rays** are best shielded with lead because of its high density. Relatively effective shields can also be made from thicker slices of less dense materials such as brick or concrete.
- **Neutrons** need to be shielded with specific elements such as boron and cadmium, or with materials containing a lot of hydrogen. For example, paraffin wax or water.

Distance is the next consideration if it is not practical to shield a radiation source, or if the shielding does not stop all the radiation. Remote handling devices such as tongs and robots have been designed to maximise the distance between the user and a source of ionising radiation. The intensity of ionising radiation falls off with the square of distance from the source, hence a short distance can provide considerable protection. In situations where the distance between a person and a radioactive source is critical to their protection (i.e. high energy sources with activities in the order of GBq—Giga i.e. 10^9), then specialist expertise should be consulted in determining the distance. Otherwise, the H&S practitioner may simply employ the method of doubling the distance from the source, as this will reduce the radiation intensity to one-quarter for people who are near to lower activity sources.

Where shielding and distance do not completely stop ionising radiation, time is the third control mechanism that may be used to protect from the external radiation hazard. Protection is obtained by reducing the time spent close to a radiation hazard. In the same way that the H&S practitioner may make a judgment regarding distance from a radioactive source, they may also make judgments regarding time, provided the activity of the source is relatively low (i.e. below the GBq range).

11.8.3 CONTROL METHODS FOR INTERNAL RADIATION HAZARDS

Shielding, distance and time controls can all be applied to minimising the external hazard associated with unsealed sources. However, additional methods are also required to protect people from the internal radiation hazard. The internal hazard can be minimised by reducing the potential for a radioisotope to enter the body.

The aim of any work with ionising radiation should be to reduce the amount of radioisotope used to a minimum. This should always be done in the planning stages of the work and should include minimising both the internal and external radiation hazard. The H&S practitioner has an instrumental role in assisting radiation users to put in place appropriate control methods to prevent radiation being ingested, inhaled or absorbed through the skin.

Cleanliness is also very important in avoiding internal contamination by unsealed radioisotopes. This includes measures such as changing gloves frequently, wearing gloves that do not absorb the radioactive materials, undertaking area monitoring frequently during an experiment, and cleaning up any spills without delay.

The third principle of protection from the internal radiation hazard is to contain radioisotopes in order to minimise the chances and the consequences of spillages. There are two types of containment:

- **Primary containment** This consists of a container immediately around the source, such as the lead pot it is stored in.
- **Secondary containment**, which is placed around the primary containment—for example, working within an impervious tray. Fume cupboards constitute secondary containment and may be used if there is a risk of vapour, or aerosol from the unsealed source.

Contamination surveys are an essential part of ensuring that good contamination control is achieved.

11.9 THE ROLE OF THE H&S PRACTITIONER WITH IONISING RADIATION HAZARDS

H&S practitioners may become involved with ionising radiation when a source is present in their workplace. Their role is generally one of identifying sources of ionising radiation, assisting in complying with any routine requirements such as registration, licensing, managing TLD badges for radiation workers within their organisation and undertaking basic surveys for contamination. Other monitoring methods, which use specialist instrumentation to measure the external radiation hazard, monitoring for the internal radiation hazard, and the prescription of most control methods for high activity sources, require the services of a health physicist or occupational hygienist with specific radiation expertise (see Section 11.1).

B: NON-IONISING RADIATION

11.10 ULTRAVIOLET RADIATION

11.10.1 PROPERTIES

Ultraviolet radiation is the highest energy non-ionising radiation and exists in three bands, from highest to lowest energy:

- **Far, short or UV-C**—wavelengths 180–280 nm and frequencies around 10^{16} Hz.
- **Middle, erythemal or UV-B**—wavelengths 280–315 nm and frequencies around 10^{15} Hz.
- **Near, long or UV-A**—wavelengths 315–400 nm and frequencies around 10^{14} Hz.

11.10.2 SOURCES

The most common source of ultraviolet radiation is the sun. Other sources capable of providing significant exposure in the occupational setting include gas and arc welding, and lamps used for applications such as:

- tanning
- scientific research

- semi-conductor memory erasing
- germicidal uses.

Plasma torches and some lasers also emit ultraviolet radiation. Lasers are discussed further in Section 11.14.

11.10.3 QUANTIFICATION AND HEALTH EFFECTS

Health effects to the skin and eyes may occur after exposure to ultraviolet radiation and are common in occupational settings if exposures are not carefully controlled.

- **Reddening (or erythema)** results from overexposure of skin in the middle and far ultraviolet range (200–315 nm), with the greatest sensitivity of skin occurring at 295 nm. Exposure to near ultraviolet on its own requires far greater levels to induce erythema; however, exposure to near and middle ultraviolet together intensifies the response.
- Chronic exposure to ultraviolet light, especially middle ultraviolet, increases **skin ageing** and the **risk of developing skin cancer**.
- The cornea and conjunctiva of the eye strongly absorb middle and far ultraviolet radiation. The resulting condition is often known as '**welder's flash**' because it often occurs after welding.

Ultraviolet radiation bands are summarised alongside possible health effects in Figure 11.7.

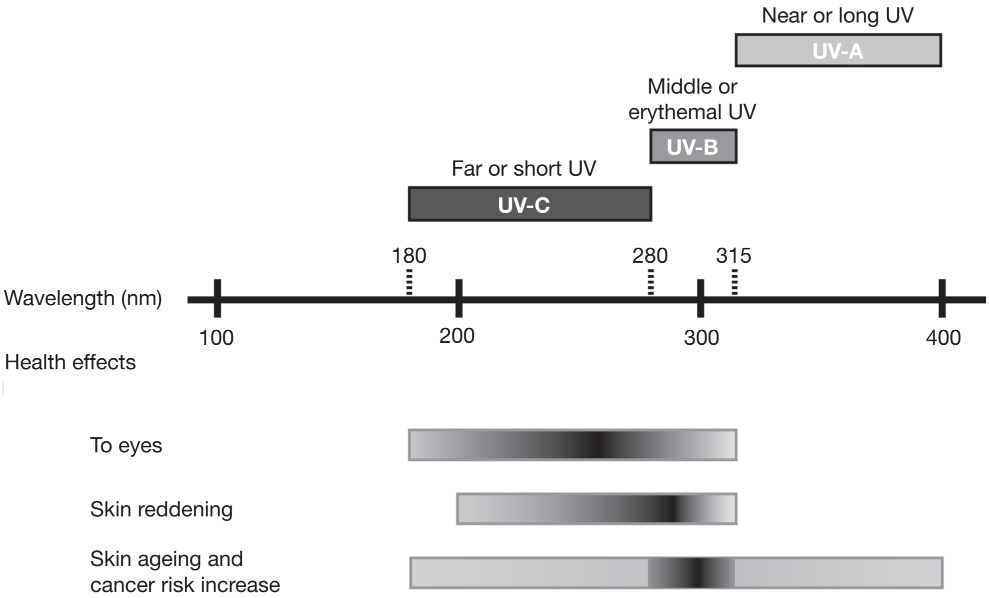

Figure 11.7 Ultraviolet radiation bands and possible health effects

Maximum allowable exposure to ultraviolet radiation is described in terms of the radiant exposure incident on the skin or eyes in units of joules per square metre (J/m^2). This varies according to the wavelength of the radiation (i.e. its relative spectral effectiveness), with the most harmful wavelength being 270 nm. Where exposure to a range of ultraviolet wavelengths occurs simultaneously, the effective irradiance (E_{eff}) in units of watt per square metre (W/m^2) is calculated in order to determine the exposure.

Instrumentation for measuring ultraviolet radiation can weight certain frequencies in terms of their relative spectral effectiveness, giving readouts in units of effective irradiance. One W is equivalent to 1 J/s, therefore effective irradiance can be used to calculate the time taken to reach a certain maximum permissible exposure to ultraviolet radiation. The measurement of ultraviolet radiation is a task usually undertaken by a professional with specific expertise in the area (see Section 11.1).

11.10.4 CONTROL METHODS

Control methods for reducing exposure to ultraviolet radiation are shielding, distance and time:

- Certain materials can be used to **shield** ultraviolet radiation. For example, clothing and hats chosen should have a formal rating for ultraviolet protection. Wide-brimmed hats and high protection factor sunscreens are also useful, but may not provide all the protection needed. Glasses for general use or faceshields for welding should meet Australian Standards® for eye and face protection. Where shields are required for industrial sources, polycarbonate or methyl methacrylate plastics absorb most ultraviolet radiation strongly. However, where a high intensity source exists the radiation may not be absorbed fully. Ultraviolet radiation can also be reflected from shiny surfaces.
- **Distance** from the source should be maximised to take advantage of the fact that the intensity of non-ionising radiation falls off rapidly as you move away from the source.
- Limiting the **time of exposure** to the source, and in the case of outdoor workers avoiding working outside without proper protective equipment during the middle of the day when ultraviolet emissions are at their maximum, can also help to reduce exposure to ultraviolet radiation.

11.11 VISIBLE AND INFRARED RADIATION

11.11.1 PROPERTIES

Visible and infrared radiations are less energetic forms of non-ionising radiation than ultraviolet. They can be described in bands from highest to lowest energy:

- **Visible light**—wavelengths 400–780 nm and frequencies around 10^{14} Hz.
- **Near infrared or IR-A**—wavelengths 780–1400 nm and frequencies around 10^{14} Hz.

- **Middle infrared or IR-B**—wavelengths 1.3–3 µm and frequencies around 10^{14} Hz.
- **Far infrared or IR-C**—wavelengths 3–1000 µm and frequencies around 10^{11}–10^{14} Hz.

11.11.2 SOURCES

Visible light comes mainly from the sun but not with sufficient intensity to be injurious to the eye unless a person stares directly at the full sun for a period of time. There are also man-made visible light sources such as incandescent lamps, lasers and gas discharge sources that produce very intense visible light. In all cases, the eye is usually protected by a person's tendency to blink or avert their gaze in response to intense light.

Infrared radiation comes mostly from the sun as heat. Transfer of infrared radiation also occurs from any object that is at a higher temperature than any other receiving object. Intense sources of infrared radiation in the workplace and the home are numerous and include heating devices such as furnaces, ovens, infrared lamps and some lasers. Lasers are discussed further in Section 11.14.

11.11.3 QUANTIFICATION AND HEALTH EFFECTS

The eye is the most vulnerable organ to visible and near infrared radiation because the wavelengths from these sources are focused on the retina where thermal or photochemical damage may result. Photochemical injury to the retina is most likely due to long exposures in the visible light region peaking at 440 nm. Thermal injury to the retina is more common with short exposures to near infrared radiation. The lens is most vulnerable to middle infrared and the formation of cataracts is common in glass-blowers unless eye protection is worn ('glass-blower's cataract'). Far infrared is absorbed at the surface of the eye and may cause superficial burns to the cornea or skin. However, skin is not usually at risk unless the source is very intense and pulsed, because a person's pain reflex generally controls the duration of exposure.

Visible and infrared bands are summarised alongside possible health effects in Figure 11.8.

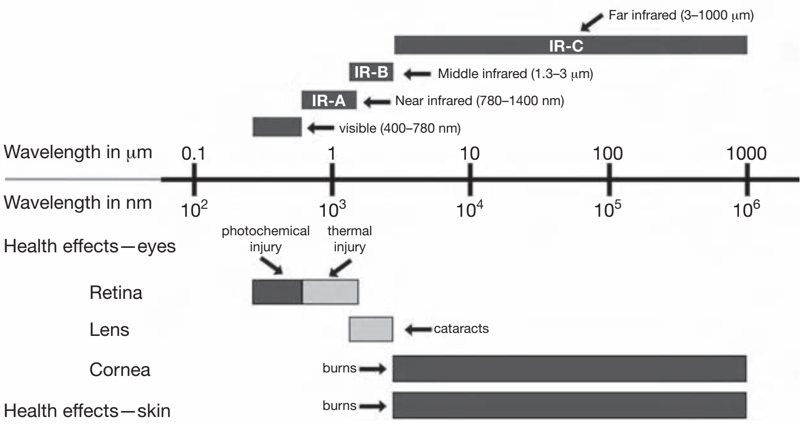

Figure 11.8 Visible and infrared bands and possible health effects

Maximum allowable exposure of the eye to visible light and near infrared radiation requires knowledge of the spectral irradiance of a particular wavelength (L_λ) and the total irradiance (E) of the source, measured at the location of the eye. This data on the hazard properties of the source is obtained using a radiometer to quantify the radiance (or 'brightness') in watts per square metre per steradian ($W/m^2.sr$), or the irradiance level on a surface, in watts per square metre (W/m^2). Once total irradiance is known, the appropriate exposure standard can be applied and a maximum permissible duration of exposure can be established.

The measurement of infrared radiation is a task usually undertaken by a professional with specific expertise in the area (see Section 11.1). However, visible light is often measured by the H&S practitioner for the purposes of workplace design. A photometer may be used to measure quantities such as luminance (brightness as perceived by a standard human observer), or illuminance (the light falling on a surface) in lux (lx) weighted to the response of the human eye. Refer to Chapter 12, Section 12.4, for a detailed coverage of lighting.

11.11.4 CONTROL METHODS

Sources of infrared radiation should be shielded close up, using reflective materials such as aluminium. Glasses or goggles are used to protect the eye and are made from plastics such as perspex or polycarbonate.

11.12 RADIOFREQUENCY RADIATION

11.12.1 PROPERTIES

Radiofrequency radiation covers the frequency range from 300 Hz to 300 GHz and has corresponding wavelengths from approximately 1000 km to 1 mm.

11.12.2 SOURCES

Microwaves and communications frequencies are the major sources of radiofrequency radiation. There are also natural sources such as Earth, the human body and the cosmos that cover a range of frequencies but are of very low exposure intensity. Man-made sources, many of which may be found in workplaces, include:

- radar
- microwave ovens
- mobile telephones
- television transmission
- FM and AM radio transmission.

Exposure to sources such as radar can be high if a person is close by. Medical uses of radiofrequency radiation include diathermy, microwave treatment and magnetic resonance imaging (MRI). These sources are in the MHz and GHz range and also have potential for high exposure intensity for the patient.

11.12.3 QUANTIFICATION AND HEALTH EFFECTS

Health effects from radiofrequency radiation may be broadly grouped as either thermal or non-thermal. Thermal effects are well established and occur when human tissue is irradiated, in the same way that water can be heated in a microwave oven. Tissues within the body are not heated uniformly and some are more sensitive to heat than others (e.g. the brain, lens, testes and the unborn child). The heating effect is also frequency dependent. For example, the ankles suffer a localised heating effect at 30–80 MHz.

Non-thermal effects include the induction of electrical currents in tissues, shocks and burns, and the microwave hearing effect whereby people report a sense of buzzing, clicking or popping in their ears. Shocks and burns are due to contact with the source of radiofrequency radiation. There is uncertainty over possible carcinogenic effects (Sanders 1996). However, reviews of current studies seem to indicate that any risk of cancer due to exposure to radiofrequency radiation is very low.

Exposure standards for radiofrequency radiation are defined as ‘basic restrictions’ and take different forms depending on the section of the radiofrequency spectrum under discussion. Basic restrictions are quantities that are impractical to measure. Thus reference levels are quantities that can be measured to assess compliance with basic restrictions. The relationship between basic restrictions and reference levels and the frequency ranges and health effects where each applies are summarised in Table 11.6 for radiofrequency radiation. Measurement of radiofrequency radiation and interpretation of the results against reference levels is best undertaken by a radiation safety professional (see Section 11.1).

11.12.4 CONTROL METHODS

Leakage of radiofrequency radiation should be controlled at the source, using shielding materials to absorb the radiation. Choosing such shielding is a specialist task as inappropriate shielding can enhance the radiofrequency field and lead to higher exposures (see Section 11.1).

In the case of communication sources, such as mobile phone antennas and radar, the radiation cannot be suppressed and care must be taken to prevent coupling between the radiofrequency fields and human bodies by preventing close access to equipment transmitting radiofrequency radiation. Conductive suits are available and can partially shield the user if fully enclosed. Such suits have the disadvantage of high thermal load and limited visibility. In addition, any opening in the suit will result in an enhanced local field.

Care should also be taken to prevent access to objects that may have large amounts of contact current in order to prevent shocks. Leather gloves are of some use in handling metal objects that may be carrying current.

Table 11.6 The relationship between basic restrictions and reference levels for radiofrequency radiation

Frequency range	Basic restriction	Reference level	Health effect
3 kHz–10 MHz	J—instantaneous, spatial peak rms	E or H (instantaneous rms) I (instantaneous contact current)	Induction of currents in tissue
100 kHz–6 GHz	SAR—average over whole body	E or H (time averaged rms)	Whole body heat stress
	SAR—spatial peak in limbs	E or H (time averaged rms) I (induced limb currents for legs and arms 10–110 MHz) I (contact point currents 100 kHz–110 MHz)	Excessive localised temperature rises in these tissues
	SAR—spatial peak in head and torso	E or H (time averaged rms)	
300 MHz–6 GHz	SA—spatial peak in head	E, H or S (instantaneous rms)	Microwave hearing effect
10 MHz–6 GHz	SAR—instantaneous spatial peak in head and torso	E, H or S (instantaneous rms)	Effects due to pulsed fields
6–300 GHz	S—time averaged and instantaneous	E or H (time averaged and instantaneous rms)	Excessive heating in surface tissue and effects due to pulsed fields

Explanation of units:

- Current density (J) in units of ampere per square metre (A/m^2)
- Electric field strength (E) in units of volts per metre (V/m)
- Magnetic field strength (H) in units of ampere per metre (A/m)
- Magnetic flux density (B) in units of tesla (T)
- Current (I) in units of ampere (A)
- Specific absorption rate (SAR) in units of watt per kilogram (W/kg) represents the rate at which energy is imparted to human tissue
- Specific absorption (SA) in units of joule per kilogram (J/kg)
- Power flux density (S) in units of watt per square metre (W/m^2)
- rms—root mean square

Source: ARPANSA (2002b)

11.13 EXTREMELY LOW FREQUENCY RADIATION AND STATIC FIELDS

11.13.1 PROPERTIES

Extremely low frequency (ELF) radiation has frequencies up to 300 Hz and wavelengths above 1000 km. Static magnetic and electric fields occur where frequency is zero Hz, and are characterised by magnetic and electric field strengths that do not change over time.

11.13.2 SOURCES

The ELF region of the electromagnetic spectrum is associated with the generation, distribution and use of electricity.

Earth has a static magnetic field produced as a result of electric current flowing in its core. Man-made static magnetic fields are usually stronger and occur around power transmission lines and induction furnaces and near apparatus having large magnets such as nuclear magnetic resonance spectrometers. Static electric fields occur where there are charged bodies and are commonly associated with the use of electricity in homes and offices and around high voltage equipment.

11.13.3 QUANTIFICATION AND HEALTH EFFECTS

Health effects for ELF radiation depend on the component electric and magnetic fields. There is little evidence showing adverse effects on human health due to static electric fields. However, it is recommended that electric field strength (E) is controlled in order to limit currents on the body surface and induced internal currents. Field strength should also be controlled in order to prevent safety hazards such as spark discharge and high contact currents on metal objects.

Health effects due to static magnetic fields include visual effects and effects on biochemistry in the body at cellular level. Magnetic field strength (H) in units of ampere per metre (A/m) and magnetic flux density (B) in units of tesla (T) are used to quantify the magnetic field.

Both electric and magnetic fields are known to interfere with cardiac pacemakers at levels of exposure that may not otherwise cause adverse health effects. There is conjecture surrounding possible carcinogenic effects due to extremely low frequency radiation and static electric and magnetic fields, but this remains unproven.

Measurement of ELF radiation and static fields is a task for a radiation specialist (see Section 11.1).

11.13.4 CONTROL METHODS

Control of ELF and static fields of radiation is a task requiring specialist expertise (see Section 11.1). ELF radiation is impractical to shield in power transmission applications. Instead, attempts are made to locate high voltage transmission lines high in the air and with a corridor of land around them in order to control the electric field strength at ground level. Magnetic field strengths are not sufficient in power transmission applications to be a health concern.

Protection from static electric fields entails grounding objects carrying current and prescribing protective suits similar to those used in radiofrequency radiation applications. Static electric fields in isolated applications may be shielded using an earthed conducting enclosure (faraday cage) and static magnetic fields may be shielded using magnetic shielding. Protection is also gained from maximising distance from the source and minimising time near to it. Metal objects need to be kept away from strong static magnetic fields as these can become missiles.

11.14 LASERS

11.14.1 PROPERTIES

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers currently produce light in the ultraviolet, visible or infrared region of the electromagnetic spectrum. However, future laser devices may generate other types of electromagnetic energy, including ionising radiation. Laser light differs from ordinary electromagnetic radiation in that the light beam is coherent in space (all the waves are in phase) and time (all the waves are of the same frequency). This means that the beam has very little divergence and is able to be transmitted large distances while retaining a relatively high level of energy per unit area. In other words, the beam from a laser remains very intense over long distances. This is in contrast to ordinary electromagnetic radiation where intensity falls off with the square of distance.

11.14.2 SOURCES

Lasers are part of a wide range of applications in industrial and commercial settings such as alignment and range finding in construction, printing, drilling, welding, cutting, advertising and entertainment. Lasers are also used in the medical field for diagnosis of internal tumours, surgery and alignment of a more powerful treatment laser.

11.14.3 HEALTH EFFECTS

The eyes and skin are the most susceptible to damage from lasers. The intensity of the beam is critical to the extent of damage caused and serious injury may occur within seconds if the beam of a powerful laser is not appropriately controlled. Reflections off smooth surfaces such as mirrors and lenses are also a significant hazard. In all other respects the health effects caused are the same as for the particular type of electromagnetic radiation being generated. Table 11.7 describes likely hazards from laser radiation under the heading ‘characteristics’.

Table 11.7 Summary of laser classes, characteristics and control measures

Laser class	Characteristics	Specific control measures
1	Safe under most circumstances including the use of optical instruments for intra-beam viewing	None
1M	Emit in the range 302.5–4000 nm, but may be hazardous if optics are used in the beam	i–iii
2	Emit visible radiation 400–700 nm where eye protection is afforded by the blink reflex including where optical instruments used for intra-beam viewing	i–iii
2M	As for class 2, except that viewing may be more hazardous if optics are used in the beam	i–iii
3R	Emit in the range 302.5–10^6 nm where direct intra-beam viewing is potentially hazardous	i–iv
3B	As for class 3R, except that direct intra-beam viewing is normally hazardous. Viewing diffuse reflections is normally safe	i–vii
4	Capable of producing hazardous diffuse reflections, skin injuries and may also be a fire hazard	i–viii

Explanation of control measures:

i	Training
ii	Beam stop or attenuator
iii	Avoid specular reflections
iv	Protective eyewear
v	Warning signs on enclosures
vi	Remote interlock to laser
vii	Key control of laser
viii	Protective clothing

Source: Derived from AS 2211.1 (Standards Australia 2004) (by the author)

11.14.4 CONTROL METHODS

Lasers are classified according to the level of risk they represent, although not all countries that manufacture lasers label them accurately in this regard. Accurate knowledge of the class of a laser provides sufficient information to enable main control measures to be put in place. A summary of laser classes, characteristics and control measures specific to each class may be found in Table 11.7.

11.15 THE ROLE OF THE H&S PRACTITIONER WITH NON-IONISING RADIATION HAZARDS

H&S practitioners may become involved with non-ionising radiation when a high intensity source such as a laser or ultraviolet lamp is present in the workplace. As with ionising radiation, the H&S practitioner's role is one of identifying sources of non-ionising radiation and prescribing some of the simpler control measures, such as hats and sunscreen for protection from outdoor ultraviolet radiation. Instrumentation and measurement of non-ionising radiation is often complex and it is easy to obtain false readings. The only exception is measuring visible light levels for consideration in workplace design. Similarly, many control methods require specialist expertise in order that a radiation hazard is not worsened. The services of a health physicist or occupational hygienist with specific radiation expertise should be sought (see Section 11.1).

11.16 REFERENCES

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12. Other physical agents

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12.1 INTRODUCTION

Work in the industrial workplace is seldom undertaken in an ideal environment and can often expose the individual to physical extremes, whether of temperature or light. This chapter looks at the impact of these parameters on the individual and outlines assessment protocols and guidelines for their management.

The mines in the Pilbara region of northern Western Australia and the snowfields of the Victorian alpine region have one thing in common—extremes of temperature and what can often be an inhospitable working environment. The human body operates best in a moderate climate and variations that can result in a lowering or increase of the core body temperature (36.8°C) can lead to serious physiological injury or illness. While the identification of such conditions is often obvious, the control and successful correction of the situation is sometimes not as straightforward, due to the myriad variations that can be involved. By taking a systematic approach to the investigation such confusion can often be overcome and practical controls identified and implemented.

12.2 WORK IN HOT ENVIRONMENTS

Workers in hot environments, around furnaces, smelters, boilers or out in the sun, can be subjected to considerable stress. Because of natural climatic conditions and outdoors life- and work-styles, many environments in Australia have a high potential for heat-related work illnesses. The H&S practitioner should be able to recognise the physical factors contributing to heat stress, how the body responds, and be familiar with control procedures for these adverse factors. This section provides a basic introduction to the concepts of heat stress and its management. More comprehensive discussion in this area may be found in specialist texts and guides such as the Australian Institute of Occupational Hygienists' *Heat Stress Standard and Documentation Developed for Use in the Australian Environment* (Di Corleto et al. 2003), from which sections of this text have been adapted.

12.2.1 HEAT STRESS AND HEAT STRAIN

It is important at the outset to define two key terms associated with work in the thermal environment. The combined effect of external thermal environment and internal metabolic heat production constitutes the **thermal stress** on the body. The levels of activity required in response to the thermal stress from bodily systems such as the cardiovascular, thermoregulatory, respiratory, renal and endocrine systems constitute the **thermal strain**. Thus environmental conditions, metabolic workload and clothing, individually or combined, can create **heat stress** for the worker. The body's physiological response to that stress, for example sweating, increased heart rate and elevated core temperature, is the **heat strain** (Di Corleto et al. 2002).

During any activity, the body automatically attempts to maintain a constant working temperature range by balancing out the heat gain and heat loss. Working creates metabolic heat, and the heat is carried by the blood to the skin. The work causes the heart to pump faster and so carries the blood faster to the surface. The body dissipates heat through the skin via the cooling mechanism provided by evaporation of sweat.

12.2.2 ACCLIMATISATION

Workers in hot environments can become acclimatised as a way of reducing the heat strain. Acclimatisation produces a lower heart rate and higher sweat rate with more dilute sweat. There are different rates of change in the acclimatisation process which have been broken up into three specific phases:

- **Initial phase** The first stage of the acclimatisation process, which usually accounts for 33 per cent of the optimum acclimatisation by day 4.
- **Intermediate phase** When cardiovascular stability has been assured and surface and internal body temperatures are lower. Usually 44 per cent of optimum is achieved by day 8, although some research carried out in northern Queensland (Brake & Bates 2001) suggests that about 70–80 per cent will be achieved after about 7–10 days.
- **Third phase** A decrease in the salt content of sweat and urine, and other compensations, to conserve body fluids and restore electrolyte balances. Usually greater than 65 per cent of optimum by day 10, 93 per cent by day 18, and 99 per cent by day 21.

It is very important to note that employees who have been on extended leave, new employees, and contract labour from a cooler climatic location, will not be acclimatised and this must be taken into consideration when scheduling work in a hot environment. Generally new workers in hot environments must be permitted 1 to 2 weeks to acclimatise.

12.2.3 THE HEAT BALANCE EQUATION

In order for the body to maintain thermal equilibrium and avoid illness or injury, a thermal balance must be maintained. This heat balance equation is given by

$$H = M \pm C \pm R \pm K - E \qquad \text{(Equation 12.1)}$$

where:

H = heat accumulation by the body
M = metabolic heat output
C = convective heat input or loss (can be positive or negative)
R = radiant heat input or loss (can be positive or negative)
K = conductive input or loss (can be positive or negative)
E = evaporative cooling by sweating (can only be negative).

12.2.4 THE BASIC FORMS OF HEAT ILLNESS

If environmental work factors prevent the body maintaining this balance because:

- air temperature is too high
- humidity is too high
- there is a high radiant heat load, or
- the worker is constricted by insulating clothing,

the body begins to experience physiological heat strain with different symptoms and illnesses depending on the degree of heat stress. The conditions of importance, ranging from least to most stressing, are:

- **Behavioural disorders** Chronic or transient simple heat fatigue often occurs in workers from colder climates who are unacclimatised to continuously hot weather. Lifestyle changes (appropriate clothing, mid-day resting) or avoiding strenuous work during the heat of the day, and acclimatisation are appropriate.
- **Heat rash** Usually occurs as a result of continued exposure to humid heat with the skin remaining continuously wet from unevaporated sweat. This can often result in blocked glands, itchy skin and reduced sweating. In some cases prickly heat can lead to lengthy periods of disablement (Donoghue & Sinclair 2000). Where conditions encourage occurrence of prickly heat (e.g. exposure to damp situations in tropical or deep underground mines), control measures may be important to prevent onset. Keeping the skin clean and as cool and dry as possible to allow the skin to recover is generally the most successful approach.
- **Heat cramps** These are characterised by painful spasms in one or more muscles. Heat cramps may occur in persons who sweat profusely in heat without replacing salt losses, or unacclimatised personnel with higher levels of salt in their sweat. Resting in a cool place and drinking 250 ml of saline solution (0.9% NaCl) will rapidly alleviate cramps. Use of salt tablets is undesirable. Counselling should be provided to ensure workers maintain a balanced electrolyte intake, with meals if possible. Note that heat cramps occur most commonly during heat exposure, but can also occur some time after heat exposure.
- **Fainting** (or **heat syncope**) Exposure of fluid-deficient persons to hot environmental conditions can cause a major shift in the body's remaining blood supply to the skin vessels in an attempt to dissipate the heat load. This ultimately results in an inadequate supply of blood being delivered to the brain and consequent fainting. Fainting may also occur without significant reduction in blood volume in conditions such as wearing restrictive or confining clothing, or with postural restrictions.
- **Heat exhaustion** While serious, heat exhaustion is initially a less severe heat injury than heatstroke, although it can become a precursor to heat stroke. Heat exhaustion is generally characterised by clammy, moist skin; weakness or extreme fatigue; nausea; headache; no excessive increase in body temperature; and low blood pressure with a weak pulse. Without prompt treatment, collapse is inevitable. Heat

exhaustion occurs most often in persons whose total blood volume has been reduced due to dehydration (i.e. depletion of body water as a consequence of deficient water intake), but can also be associated with inadequate salt intake even when fluid intake is adequate. Individuals who have a low level of cardiovascular fitness and/or are not acclimatised to heat have a high potential to suffer heat exhaustion, sometimes recurrently. This is particularly where self-pacing of work is not practised. Note that where self-pacing is practised, both fit and unfit workers tend to have a similar frequency of heat exhaustion (Brake & Bates 2001). Lying down in a cool place and drinking cool, slightly salted water (0.1% NaCl), or an electrolyte supplement, will usually result in rapid recovery of the victim of heat exhaustion, but a physician should be consulted prior to resumption of work. Salt-depletion heat exhaustion may require further medical treatment under supervision.
- **Heatstroke** This is a state of thermoregulatory failure and is the most serious of the heat illnesses. Heatstroke is usually considered to be characterised by hot, dry skin; rapidly rising body temperature; collapse; loss of consciousness; and convulsions. If deep body temperature exceeds 40°C, the danger of heatstroke is imminent. Without prompt and appropriate medical attention, including removal of the victim to a cool area and applying a suitable method for reduction of the rapidly increasing body temperature, heatstroke will be fatal. Immediate cooling is necessary to reduce the body core temperature to below 39°C. It has been suggested that the traditional method of immersion of the body in an ice bath should be replaced by the method developed for the many heat casualties regularly occurring in the Mecca pilgrimage (Weiner & Khogali 1980; Khogali 1987), that is, to spray the patient with cool water and fan to create evaporation. **A heatstroke victim needs immediate, experienced medical attention.**

12.2.5 FACTORS INFLUENCING HEAT STRESS

Heat gain by the working body is derived from several sources:

- **Muscular activity** from the work. As the muscles of the body undertake work and oxygen is consumed, heat is released, which increases core temperature.
- **Conductive and convective heat** from working in hot air. In some cases, heat is picked up from handling hot objects. Cool air can cool the body directly. If air temperature is hotter than body temperature, heat flows from the hotter air to the cooler skin surface. Air speed is also very important in workplace cooling because it influences evaporation rate and convective cooling. Normal skin temperature is around 35°C.
- **Radiant heat** from nearby or distant hot bodies. Hot bodies radiate heat in the infrared region which passes through air (or vacuum), heating it very little. The energy is absorbed by the body of the worker, by equipment in the workplace, etcetera. This is a major factor contributing to heat stress.

12.2.6 FLUID INTAKE AND THIRST

The importance of adequate fluid intake and the maintenance of correct bodily electrolyte balance cannot be overemphasised. Maintaining the heat balance in the body in heat stress conditions demands the production and evaporation of enough sweat to produce sufficient evaporative cooling to balance the heat gain from the environment and metabolic workload. Sweat production is limited by the upper limit of fluid absorption from the digestive tract and the acceptable degree of dehydration once maximum fluid intake has been achieved. It has been found that the limit of the stomach and gut to absorb water is between 1.6 and 1.8 L/hr over many hours providing the individual is not dehydrated (Brake et al. 1998). Physiological effects from dehydration may commence at 1.5–2.0 per cent dehydration. Net fluid loss of 5 per cent in an occupational setting is considered severe dehydration.

Thirst is an inadequate indicator for the replacement of fluids in an occupational environment. In most cases individuals would already be experiencing some degree of dehydration at the onset of thirst. Workers should be encouraged to drink small amounts of water frequently rather than larger quantities infrequently. The water should be cool (10–15°C) and be available close to the workplace. In some cases it may be desirable to flavour the water to make it more palatable, but a low-sugar flavouring should be used. It should be noted that high solute levels reduce the rate of absorption in the gastrointestinal system. Caffeine and alcohol are diuretics and hence increase water loss. In situations where there is a high loss of fluid, electrolyte replacement may also be required. In most situations dietary salt intake is sufficient to maintain salt requirements for acclimatised individuals. With unacclimatised workers maintaining a high level of fluid intake in a high heat stress scenario, a deficiency in electrolyte can still occur. In such situations salt tablets should not be used for electrolyte replacement—there are a number of commercially available electrolyte replacement drinks that can be used sparingly under medical direction to fulfil this role. Table 12.1 lists the advantages and disadvantages of a number of drinks commonly used for fluid replacement.

12.2.7 TRAINING

Training is a key component in any health management program. In relation to heat stress it should be conducted for all personnel likely to be involved with:

- hot environments
- physically demanding work at elevated temperatures
- the use of impermeable protective clothing.

Any combination of the above situations will further increase the risk.

The training should encompass the following:

- mechanisms of heat exposure
- potential heat exposure situations
- recognition of predisposing factors

Table 12.1 Analysis of fluid replacement

Beverage type	Uses	Advantages	Disadvantages
Sports drinks	Before, during and after work	• Provide energy • Aid electrolyte replacement • Palatable	• May not be correct mix • Excessive use may exceed salt replacement requirement levels • Low pH levels may affect teeth
Fruit juices	Recovery	• Provide energy • Palatable • Low in sodium	• Not absorbed rapidly
Carbonated drinks	Recovery	• Palatable • Variety of flavours • Provides potassium • Low sodium • Quick 'fillingness'	• Belching • 'Diet' drinks have no energy • Risk of dental cavities • Some may contain caffeine
Water and mineral water	Before, during and after exercise	• Palatable • Most obvious fluid • Readily available • Low sodium	• Not as good for high output events of 60 mins + • No energy
Milk	Before and after recovery	• Contains sodium • Has some energy • Use with fruit, cereal	• Slowly absorbed • Has fat • Not suitable during an event

Source: Adapted from Pearce (1996)

- the importance of fluid intake
- the nature of acclimatisation
- effects of alcohol and drug use in hot environments
- early recognition of symptoms of heat illness
- prevention of heat illness
- first aid treatment of heat-related illnesses
- self-assessment
- management and control
- medical surveillance programs and the advantages of employee participation in such programs.

Training of all personnel in heat stress management should be recorded on their personal training record.

12.2.8 SELF-ASSESSMENT

Self-assessment is a key element in the training of individuals potentially exposed to heat stress. With the correct knowledge in relation to signs and symptoms, individuals will be in a position to identify the onset of a heat illness in the very early stages and take the appropriate actions. This may simply involve taking a short break and a drink of water, which in most cases should take only a matter of minutes. This brief intervention can significantly help in the prevention of the onset of the more serious heat-related illnesses, particularly when associated with the acceptance of self-pacing of work activities.

12.2.9 ASSESSMENT OF THE THERMAL ENVIRONMENT

Numerous factors can impact on the heat stress associated with a particular task or environment and no single factor can be assessed in isolation. A structured assessment protocol is the suggested approach, with the flexibility to meet the occasion.

The sole use of a heat stress index for the determination of heat stress and the resultant heat strain is not recommended. Each situation requires an assessment that will incorporate the many parameters that may impact on an individual in undertaking work in elevated thermal conditions. In effect, a risk assessment must be carried out which includes additional observations such as workload, worker characteristics and personal protective equipment, as well as measurement and calculation of the thermal environment. This process may involve a variety of heat stress indices which may include, but is not limited to: wet bulb globe temperature, predicted heat strain, basic effective temperature and thermal work limit.

Wet bulb globe temperature (WBGT) uses air temperature (Ta), globe temperature (Tg) and a natural wet bulb temperature (Tnwb). These parameters are incorporated into one of two formulas for either indoor or outdoor measurements:

$$\text{Indoor:} \quad \text{WBGT} = 0.7\ \text{Tnwb} + 0.3\ \text{Tg} \qquad \text{(Equation 12.2)}$$

$$\text{Outdoor:} \quad \text{WBGT} = 0.7\ \text{Tnwb} + 0.2\ \text{Tg} + 0.1\ \text{Ta} \qquad \text{(Equation 12.3)}$$

Predicted heat strain (PHS) is a rational index (i.e. it is an index based on the heat balance equation; see Section 12.2.3). It estimates the required evaporation rate and the maximal evaporation rate, utilising the ratio of the two as an initial measure of 'required wettedness'. This required wettedness is the fraction of the skin surface that would have to be covered by sweat in order for the required evaporation rate to occur. The evaporation rate required to maintain a heat balance is then calculated (Di Corleto et al. 2003).

The basic effective temperature (BET) is predominantly used in the underground mining industry and combines dry bulb and wet bulb temperatures with air velocity.

The thermal work limit (TWL) was developed in Australia in the underground mining industry by Brake and Bates (2002). TWL is defined as the limiting (or maximum) sustainable metabolic rate that hydrated, acclimatised individuals can maintain in a specific thermal environment, within a safe deep body core temperature (<38.2°C) and sweat rate (<1.2 kg/hr).

A recommended method of assessment is as follows:

- **Stage 1** A basic heat stress risk assessment incorporating a simple index (e.g. WBGT, BET, etc.) and a basic review of the task and the environment.
- **Stage 2** If a potential problem is indicated from the initial step, then progress to a second level index (i.e. PHS, TWL, etc.) to make a more comprehensive investigation of the situation and general environment. Ensure factors such as temperature, radiant heat load, air velocity, humidity, clothing, metabolic load, posture and acclimatisation are taken into account.
- **Stage 3** Where the calculated allowable exposure time is less than 30 minutes or there is an involvement of high-level personal protective equipment, then employ some form of physiological monitoring.

The first two stages involve measuring the environmental factors, and measuring metabolic work rate factors and/or estimating workload factors from task observation and typical comparable information. The third stage looks at the individual's physiological reaction to the exposure. With modern technology, there are methods for measuring deep core temperature, such as swallowing a continuous radio-transmitting temperature sensor in a stainless steel capsule. However, for the average H&S practitioner, such advanced techniques or other physiological measurements have obvious practical limitations.

12.2.10 STAGE 1: BASIC RISK ASSESSMENT

The first level of assessment utilises a basic observational risk assessment in conjunction with the WBGT index. The evaluation of potentially hazardous situations involving heat stress lends itself to this approach. It is important that the initial assessment involves a review of the work conditions, the task and the personnel involved. Risk assessments may be carried out using checklists or proformas designed to prompt the assessor to identify potential problem areas. The method may range in its simplest form from a short checklist through to a more comprehensive calculation matrix, which will produce a numerical result for comparative or priority listing.

A basic thermal risk assessment, such as that used in the AIOH guidelines (Di Corleto et al 2003) and illustrated in Table 12.2, is a simple first approach. The table incorporates a number of factors which impact on the potential heat stress of an individual. These factors are given a numerical value and weighted according to their potential impact. The values are then used in a simple calculation which results in a numerical value that may be used to assess the potential risk according to a predetermined scale. This approach encourages the individual or team assessing the situation to review a number of parameters and not focus solely on one measure such as air temperature. The WBGT assists with the final result by adding a level of environmental measurement and objectivity.

The WBGT index provides the most common, convenient measure for heat stress evaluations. To determine WBGT, measurements are needed of the following:

- dry bulb air temperature
- wet bulb air temperature
- radiant globe temperature.

Commercial instrumentation (e.g. Figure 12.1) is readily accessible to measure WBGT and can be either purchased or hired from a number of providers. This instrument measures the globe temperature, the natural wet bulb and a shielded dry bulb air temperature to be utilised for WBGT measurements. Modern instruments will automatically do the indoor/outdoor calculations for the user.

Three simple temperature measurements will provide the same information.

1. Measure the dry air temperature in the workplace with a thermometer (e.g. mercury in glass or thermocouple junction) shielded from radiant energy.
2. Measure the natural wet bulb temperature at the same point in the workplace, shielded again from radiant energy. The wet bulb is a standard thermometer in which the temperature sensing element is enclosed with a wick immersed in distilled water. This temperature reading will take into account the humidity of the air (hence ability to cool by evaporation) and the air movement which aids cooling by sweat evaporation from the skin.
3. Measure the globe temperature, which is a reflection of the radiant energy reaching the thermometer. The globe thermometer is mounted inside a blackened globe of 15 cm diameter. Allow 20 minutes to reach equilibrium.

Figure 12.1
A modern wet bulb globe temperature (WBGT) instrument

Calculate the WBGT index for the work circumstance (indoor or outdoor) from the appropriate equation (12.4 or 12.5).

For indoor or outdoor exposure with no heating by the sun:

$$\text{WBGT} = 0.7\ \text{Tnwb} + 0.3\ \text{Tg} \qquad \text{(Equation 12.4)}$$

and for outdoor exposure in the sun:

$$\text{WBGT} = 0.7\ \text{Tnwb} + 0.2\ \text{Tg} + 0.1\ \text{Ta} \qquad \text{(Equation 12.5)}$$

where:

Tnwb = wet bulb temperature
Tg = globe temperature
Ta = dry bulb air temperature

12.2.11 WORKED EXAMPLE OF BASIC THERMAL RISK ASSESSMENT

A fitter is working outside at ground level on a pump that has been taken out of service the previous day. The task involves removing bolts and a casing to check the impellers for wear, which takes approximately 2 hours. The pump is situated approximately 25 metres from the workshop where the fitter is based. The fitter is acclimatised, has attended a training session, is wearing a standard single-layer long shirt and trousers, and a respirator is not required. The work rate is light, there is a light breeze and the WBGT temperature has been measured at 27°C.

An example of the application of the basic thermal risk assessment using this information is given in Table 12.2.

Subtotal A = 15 This is a general measure of the working environment (excluding temperature) and some key influencing factors associated with heat stress.

Subtotal B = 2 This evaluates the metabolic load on the individual (i.e. the intensity of work being undertaken in the task).

Subtotal C = 2 Here the assessment incorporates the actual environmental temperatures using the WBGT index. As this is an important factor in the scenario it is given added weight by using a multiplication factor rather than addition.

The formula used to arrive at the numerical assessment of risk is $(A + B) \times C$. Hence, the total $= (15 + 2) \times 2 = 34$.

- If the total is **less than 28** then the risk due to thermal conditions is low to moderate.
- If the total is **28 to 60** there is a potential of heat-induced illnesses occurring if the conditions are not addressed. Further analysis of heat stress risk is required.
- If the total **exceeds 60** then the onset of a heat-induced illness is very likely and action should be taken as soon as possible to implement controls.

Table 12.2 Worked example of basic thermal risk assessment

Assessment factor	**Assessment point value**			
	1	**2**	**3**	
Hot surfaces	Contact neutral ☑	Hot on contact ☐	Burn on contact ☐	
Exposure period	<30 mins ☐	30 mins–2 hrs ☑	2 hrs ☐	
Confined space	No ☑		Yes ☐	
Task complexity	Simple ☐	Moderate ☑	Complex ☐	
Climbing, ascending, descending	None ☑	Moderate ☐	Significant ☐	
Distance from cool rest area	<50 m ☑	50–100 m ☐	>100 m ☐	
Distance from drinking water	<30 m ☑	30–50 m ☐	>50 m ☐	
Clothing (permeable)	Single layer (minimum) ☑	Single layer (moderate) ☐	Multiple layers ☐	
Understanding of heat strain risk	Training given ☑		No training given ☐	
Air movement	Windy ☐	Some wind ☑	No wind ☐	
Respiratory protection (-ve pressure)	None ☑	Half-face ☐	Full-face ☐	
Acclimatisation	Acclimatised ☑		Unacclimatised ☐	
	9	6	0	
SUBTOTAL A:			15	
	2	**4**	**6**	
Metabolic work rate*	Light ☑	Moderate ☐	Heavy ☐	
SUBTOTAL B:			2	
	1	**2**	**3**	**4**
Wet bulb globe temperature	<24°C ☐	>24°C ≤27°C ☑	>27°C ≤30°C ☐	>30°C ☐
SUBTOTAL C:			2	

* *Notes*:

- **Light work** Sitting or standing to control machines; hand and arm work assembly or sorting of light materials.
- **Moderate work** Sustained hand and arm work such as hammering, handling of moderately heavy materials.
- **Heavy work** Pick and shovel work, continuous axe work, and carrying loads up stairs.

As the total lies between 28 and 60 there is a potential for heat-induced illness occurring if the conditions are not addressed, and further, more comprehensive analysis of heat stress risk or implementation of controls is required.

12.2.12 STAGE 2 OF THE ASSESSMENT

When stage 1 of an assessment indicates that the conditions may be unacceptable, as in the above example, relatively simple and practical control measures should be considered. Where these are unavailable, a more detailed assessment is required. This stage usually involves a more extensive measurement survey of the environment including humidity, air velocity, clothing, posture and metabolic load. These additional data would then be used in a higher level heat stress index such as the rational index ISO 7933 *Predicted Heat Strain* (ISO 2004), or other indices with extensive supporting physiological documentation. Assessments at this level require technical interpretation, and assistance may be required from a suitably qualified specialist such as an occupational hygienist. The number of calculations required with rational indices necessitates the use of pre-programmed instrumentation, a computer program or a calculation spreadsheet. For ISO 7933, a program is freely available for download (Malchaire 2003). This program allows calculation of predicted body core temperatures for specific environmental conditions and workloads for a number of task or work phases, and can be used as a guide to the development of controls. It should always be remembered that these tools are guides only and should not be used for the development of absolute safe/unsafe limits.

A heat stress risk assessment checklist should also be used as part of the stage 2 process to ensure a comprehensive assessment is undertaken. An example of a suitable checklist is presented in Table 12.3.

Table 12.3 Heat stress risk assessment impacts

Assessment parameter	**Impact**
Dry bulb temperature	Elevated temperatures will add to the overall heat burden
Globe temperature	Will give some indication as to the radiant heat load
Air movement—wind speed	Poor air movement will reduce the effectiveness of sweat evaporation; high air movements at high temperatures (>42°C) will add to the heat load
Humidity	High humidity is also detrimental to sweat evaporation
Hot surfaces	Can produce radiant heat as well as result in contact burns
Metabolic work rate	Elevated work rates can potentially increase internal core body temperatures

Exposure period	Extended periods of exposure can increase heat stress
Confined space	Normally results in poor air movement and increased temperatures
Task complexity	Will require more concentration and manipulation
Climbing, ascending, descending—work rate increase	Can increase metabolic load on the body
Distance from cool rest area	Long distances may be disincentive to leave hot work area or seen as time wasting
Distance from drinking water	Prevents adequate rehydration

Employee condition	**Impact**
Medications	Diuretics, some antidepressants and anticholinergics may affect the body's ability to manage heat
Chronic conditions, i.e. heart or circulatory	May result in poor blood circulation and reduced body cooling
Acute infections, i.e. colds, influenza, fevers	Will impact on how the body handles heat stress, i.e. thermoregulation
Acclimatisation	Poor acclimatisation will result in poorer tolerance of heat, i.e. less sweating, more salt loss
Obesity	Excessive weight will increase the risk of a heat illness
Age	Older individuals (>50) may cope less well with the heat
Fitness	A low level of fitness reduces cardiovascular and aerobic capacity
Alcohol in last 24 hours	Will increase the likelihood of dehydration

Chemical exposure factors	**Impact**
Gases, vapours and dusts soluble in sweat	May result in chemical irritation/burns and dermatitis
Impermeable clothing	Significantly affects the body's ability to cool
Respiratory protection (negative pressure)	Will affect the breathing rate and add an additional stress on the worker
Increased workload due to PPE	Items such as SCBA will add weight and increase metabolic load
Restricted mobility	Will affect posture and positioning of employee

Figure 12.2
Use of a portable WBGT in an indoor industrial setting

Figure 12.2 shows a simple, practical portable device for WBGT measurements, being used to measure temperatures in a hot area of an aluminium smelter.

12.2.13 STAGE 3: INDIVIDUAL HEAT STRESS MONITORING

There are circumstances where rational indices cannot assure the safety of the exposed workgroup and hence the use of individual physiological monitoring may be required. These may include situations of high heat stress risk or where the individual's working environment cannot be accurately assessed. A common example is work involving the use of encapsulating suits.

Instrumentation is available for personal heat stress monitoring. These instruments do not measure the environmental conditions leading to heat stress, but rather they monitor the physiological indicators of heat strain—usually body temperature and/or heart rate. Temperature may be measured from a number of areas of the body, including oral, rectal, aural (ear canal or tympanic), oesophageal, skin and internal telemetry. Each of these methods (measuring heart rate and body temperature) has advantages and drawbacks. It is important that the method chosen not only provides the required data but is also acceptable to the individual being monitored.

Figure 12.3 shows a personal heat stress monitor available commercially which measures the wearer's heart rate via a sensor worn on the chest, and temperature via a sensor located elsewhere on the skin. This instrument uses heart rate and surrogate core temperature to monitor and evaluate physiological condition. The temperature it records is not a true core temperature, as the measurement is taken externally via a sensor placed on the skin. The instrument converts the measurement to a surrogate

Figure 12.3 Personal heat stress monitor

(predicted) core temperature using a built-in algorithm. It is small, lightweight, can be slipped into a shirt pocket or worn on a belt, and is fitted with an audible indicator to warn of stressing conditions. Thresholds are not fixed for heart rate or temperature, but are established as the physiological measurements are taken.

Such instruments provide a logged time history graph which may be downloaded to a computer for further analysis. Depending on the situation, physiological monitoring can be complex. Where assessment indicates it is necessary, it must be undertaken by a competent person with proven technical skills and experience in heat stress and/or human physiology. H&S practitioners involved in industries where heat stress is a continuing problem may find this approach very useful. A good example of such a situation is the stripping of asbestos while dressed in impermeable plastic clothing, a practice not at all suitable for tropical and subtropical climates.

12.2.14 PRE-PLACEMENT HEALTH ASSESSMENT

Pre-placement health assessment screening should be considered for identifying those susceptible to systemic heat injury, or for tasks with high heat stress exposures. The standard ISO 12894 *Ergonomics of the Thermal Environment* (ISO 2001) provides guidance for medical supervision of individuals exposed to extreme heat. Health assessment screening should consider the worker's physiological and biomedical aspects, and provide an interpretation of job fitness for the jobs to be performed. Only specific indicators of heat intolerance should be targeted.

Some workers may be more susceptible to heat stress than others. These workers include those who:

- are dehydrated
- are unacclimatised to workplace heat levels
- are physically unfit
- have low aerobic capacity, as measured by maximal oxygen consumption
- are overweight (Body Mass Index or BMI should preferably be below 24–27)
- are more than 50 years old
- suffer from diabetes
- suffer from hypertension
- suffer from heart, circulatory or skin disorders
- suffer from thyroid disease
- are anaemic
- use medications that impair temperature regulation or perspiration.

Workers with a history of renal, neuromuscular or respiratory disorder, or previous head injury or fainting spells, or previous susceptibility to heat illness, may also be at risk (Brake, Donoghue & Bates 1998; Hanson & Graveling 1997). Those more at risk might be excluded from certain work conditions or be medically assessed more frequently.

Short-term disorders and illnesses such as colds or flu, diarrhoea, vomiting, lack of sleep and hangover should also be considered. These will inhibit the individual's ability to cope with heat stress and hence make them more susceptible to an onset of heat illness.

12.2.15 SETTING LIMITS FOR HEAT EXPOSURE

As can be seen from the preceding section, there are numerous variables associated with individual wellbeing that can impact on workers' reaction to heat. Add to this climatic variables such as humidity and air speed, the clothing required for the job, then add the workload itself, and an extremely complex equation develops. It is for this reason that the practice of selecting a single parameter such as air temperature as a work/no-work limit is dangerous. It is impossible to select any one temperature that is suitable for work for all individuals and tasks. Heavy work at temperatures not normally classed as elevated can produce just as significant a heat stress risk as low workloads at higher temperatures. A temperature of 35°C at 15 per cent humidity is more tolerable than 30°C at 95 per cent humidity. Adding individual variation in health and fitness shows how difficult it would be to select a single valid temperature. Using the one temperature principle it is quite possible to overprotect some workers in a group and have an individual in the same group being at risk. Management of heat stress is about looking at the total picture rather than one easily measured parameter.

12.2.16 CONTROL MEASURES AGAINST HEAT STRESS

A number of workplace engineering, environmental and task factors can be varied to reduce heat stress. From the data collected in the risk assessment and measurement stages, controls may be determined. These may include:

- Reducing the workload factor by mechanising some tasks.
- Reducing radiant heat load by:
  - lowering temperature of hot processes or changing emissivity of the hot surface
  - relocating hot processes
  - using heat shields, reflective protective equipment, and heat shielding clothing.
- Increasing air speed with fans if air temperature is <38°C, and shedding clothing.
- Decreasing air speed if air temperature is >42°C.
- Dehumidifying air to increase evaporative cooling from sweating, perhaps by eliminating all sources of water vapour from leaks in steam lines or standing water evaporating from floors.
- Limiting the time exposure to the hot work by, for example:
  - carrying out hot tasks in the cool of morning or evening
  - providing cool areas for recovery
  - using extra manpower to reduce exposure time for each worker.
- Restricting overtime work in hot environments.
- Providing specialised vortex air-cooled or ice/phase change vests for some continuous demand tasks.

In addition, worker training and selection is important. Attention should be paid to the following:

- heat acclimatisation
- appropriate levels of physical fitness
- adherence to a liquid replacement schedule
- maintenance of electrolyte balance in body fluids, especially for unacclimatised workers
- training of supervisors and workers in the recognition of various heat illnesses
- information for workers on the impact of drugs, alcohol and obesity on heat illnesses
- screening workers for heat intolerance (particularly previous episodes)
- seasonal factors relating to climate.

Application of these guidelines should ensure workplaces which are free of heat stress conditions. Illness from heat stress is totally preventable.

12.3 WORK IN COLD CLIMATES

Most concerns relating to work in cold conditions occur in countries or places where snow falls during winter and outdoor work must continue. Cold is also relevant to work in freezer plants, cold-storage facilities and for a few outdoor occupations in winter. Efforts in the prevention of cold-related health problems are directed towards the maintenance of body heat.

The body responds to cold by constricting blood vessels of the skin and shivering. The body's thermometer is the hypothalamus; it controls the blood flow to the skin and also sends signals to create more heat. Glucose can be produced as a fuel, and the involuntary shivering creates metabolic heat. As a result of severe cold, nerve reactions are slowed and hands may fumble, thus presenting additional safety hazards.

12.3.1 HEALTH EFFECTS OF EXPOSURE TO EXTREMES OF COLD

Localised effects include frostbite and chilblains which occur when insufficient blood reaches the extremities and the fluids around cells actually freeze. This causes tissue damage and can occur on fingers, toes, nose, cheeks and ears. Frostbite can occur when very cold objects are handled. A sensation of coldness initially occurs, followed by numbness. Frostbite occurs in three degrees: freezing, freezing with blistering or peeling, and freezing with tissue death.

Generalised effects of exposure to severe cold include uncontrollable shivering accompanied by slowing heart rate and a decrease in blood pressure. Speech may slur and incoherence, drowsiness, irregular breathing and cool skin may all be noted as body core temperature drops to the low 30s. Serious problems occur at a body temperature below 30°C. Thermoregulation breaks down, heat loss becomes pronounced and the respiratory rate decreases markedly. Popular remedies involving alcoholic drinks as a means of keeping warm can be dangerous because they exacerbate heat loss by dilating surface blood vessels.

12.3.2 PREVENTION AND CONTROL MEASURES

The main factors contributing to cold injuries are humidity, wind contact with cold bodies, improper clothing and general state of health.

Wind chill, in which the wind blows away insulating layers of air near to the body, can turn conditions which are cold into bitterly cold. This wind-chill factor is so significant for working in the cold that threshold limit values (TLVs®) (Table 12.4) are calculated on workload and the wind speed. Australia does not have standards for exposure to the cold but the TLV® table, developed in North America, can be used.

Other factors of relevance are:

- Acclimatisation to cold conditions can have a beneficial, though small, effect.
- Cold air is often very dry, and insidious dehydration via loss through the skin must be prevented by consumption of warm, non-alcoholic drinks.
- Salt balance is best controlled by normal dietary means.
- Engineering controls can include:
  - provision of wind shields outdoors, or against circulated air indoors in freezer rooms
  - provision of local heating, hot air jets, radiant heating if bare hands have to be used
  - avoiding metal tools
  - avoiding seats for low temperature work (< –1°C)
  - use of powered equipment to reduce physical workload
  - heated shelters for recovery or, if possible, for working in.
- Administrative controls can include:
  - staying within the TLVs® for cold work (this involves measuring air temperature and wind speed and minimising work in cold)
  - maintaining a schedule of rest and liquid refreshment

Table 12.4 Threshold limit values as work/warm-up schedule for a 4-hour shift

	No noticeable wind		**8 km/h wind speed**		**15 km/h wind speed**		**25 km/h wind speed**		**35 km/h wind speed**	
Air temp °C (approx), sunny sky	**Max work (mins)**	**No. of breaks**	**Max work (mins)**	**No. of breaks**	**Max work (mins)**	**No. of breaks**	**Max work (mins)**	**No. of breaks**	**Max work (mins)**	**No. of breaks**
–26 to –28	(Norm. breaks)	1	(Norm. breaks)	1	75	2	55	3	40	4
–29 to –31	(Norm. breaks)	1	75	2	55	3	40	4	30	5
–32 to –34	75	2	55	3	40	4	30	5	EWO*	
–35 to –37	55	3	40	4	30	5	EWO*			
–38 to –39	40	4	30	5	EWO*					
–40 to –42	30	5	EWO*							
–43 and below	EWO*									

Notes:

1. Schedule applies to any 4-hour work period with moderate to heavy work activity, with warm-up periods of 10 minutes in a warm location and with an extended break (e.g. lunch) at the end of the 4-hour work period in a warm location.
2. Examples of wind movement are: 8 km/h: light flag moves; 15 km/h: light flag fully extended; 25 km/h: raises newspaper sheet; 35 km/h: blowing and drifting snow.
3. TLVs® apply only for workers who are dressed in dry clothing.

For more detailed instruction on the use of the table refer to the ACGIH® TLVs® and BEIs® (2005) booklet.

*EWO = emergency work only

Source: Adapted from Occupational Health and Safety Division, Saskatchewan Department of Labour, Canada. Reproduced by permission of the American Conference of Governmental Industrial Hygienists.

- – having an adequate workforce
- – using the least cold part of the day for the coldest work (i.e. work with the highest exposure potential)
- – instructing workers to recognise and act on adverse effects of cold
- – avoiding long shifts or excessive overtime in the cold.

Personal protective equipment (PPE) involves the provision of correct and adequate clothing. Work in cold environments is one of the few work situations where PPE is the first line of defence. Layers of clothing provide a number of insulating air layers. The clothing must be permeable to sweat—inner layers of cotton are ideal.

Particular attention must be paid to the hands, the feet and the head, which is a large heat emitter.

12.4 LIGHTING

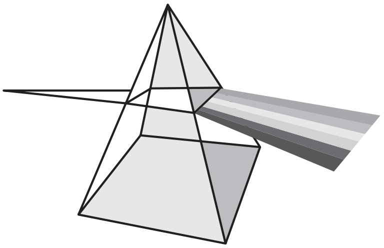
12.4.1 INTRODUCTION

Man is a light-dependent being. Without light, life on Earth would not be possible and, while all our senses are important, our sense of vision is recognised as being our most important link with our surroundings. Approximately 80 per cent of all information to be processed by our brain is received by way of our eyes, and this has a major influence on the way we function. Our sense of sight depends upon light; this may be natural light (sunlight), sunlight reflected by the moon (moonlight) or artificial light.

The rest of this chapter looks at the basics of lighting. It discusses some of the most familiar types of lamps and lighting, the eye and vision, and the eye's response to different light levels. In the context of the work environment, good lighting is essential for safety, but as this chapter demonstrates, there are issues related to the quality of light, as well as the quantity, which need to be considered in the design of workplace lighting. In this regard, the ergonomics of lighting are briefly described to show how workers operate at optimal performance levels in a well-lit environment. Finally, there is a discussion of the physiological effects of light. In recent years, considerable literature has been published on the response of organs such as the pineal gland to light, and its impact on the neuroendocrine system. Light has been shown to influence the body's circadian rhythms, and light is also a factor in some disorders, as well as being a therapeutic agent for others. These considerations are all relevant to the design of the lit environment.

12.4.2 LIGHT

Light is electromagnetic (EM) radiation in the visible region. The visible light spectrum ranges from approximately 380–770 nanometres (nm), with violet light having the shortest and red the longest wavelengths. Immediately below the visible spectrum is the ultraviolet region of the electromagnetic spectrum, while the infrared region lies immediately above it. Light may be natural, from sources such as the sun, or it may be artificial, from sources such as lamps.



The visible light spectrum is comprised as follows:

<400 nm	violet
450 nm	blue
500 nm	blue-green
550 nm	greenish yellow
600 nm	orange
650–750 nm	red

Figure 12.4 The visible spectrum

12.4.3 WHY IS LIGHTING IMPORTANT?

In industrial or office settings, proper lighting makes all work tasks easier. People receive about 80 per cent of their information through their sense of sight. Appropriate lighting, without glare or shadows, can reduce eye fatigue and headaches. It highlights moving machinery and other safety hazards. It also reduces the chance of accidents and injuries from 'momentary blindness', which occurs while the eyes adjust to significantly brighter or darker surroundings.

The ability to 'see' at work depends not only on lighting but also on:

- the time to focus on an object. Fast moving objects are hard to see.
- the size of an object. Very small objects are hard to see.
- brightness. Too much or too little reflected light makes objects hard to see.
- contrast between an object and its immediate background. Too little contrast makes it hard to distinguish an object from the background.

Light possesses wavelike properties, which are significant in relation to the optical function of the eye and how images are perceived. These wavelike properties enable light to be focused, reflected and refracted like other waves. These properties provide for the sense of vision, as light is reflected off surfaces, refracted by the lens of the eye and focused to form an image on the retina.

12.4.4 TYPES OF LAMPS AND LIGHTING

A lamp is an energy transformer that transforms electrical energy into visible EM radiation. Electromagnetic radiation is a form of energy. The spectrum of such radiation provides information on its energy composition. The entire spectrum of electromagnetic radiation ranges from X-ray radiation at the high energy, short wave end to radio waves at the low energy, long wave end. Visible light is only that small section of electromagnetic radiation which produces a sensation of brightness and colour in the human eye. Forster (1998) gives a good review of this subject.

12.4.4.1 Incandescent lamps

The oldest and still the most widespread way of generating light is by bringing a solid body to incandescence by heating. When solids and liquids are heated above 1000 K (approximately 726°C), they emit radiation as visible light. (The Kelvin, K, is the base SI unit of thermodynamic temperature; symbol K. It is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.) The solid body may be extremely small, like the glowing carbon particles in the flame of a candle, or of appreciable size, like a gas mantle or the filament of a lamp. When an object is heated, it emits light. A hot object emits a broad spectrum of light. However, the frequency and wavelength at which most of the light is emitted depends on the temperature of the object. The hotter the object, the shorter the wavelength of the energy emitted. That is, the hotter the object, the greater the energy emitted.

Observing a piece of metal in a very hot flame will demonstrate this relationship. When the metal starts to heat up, it initially glows a dull red colour. As it becomes hotter, the colour becomes a brighter red, then yellow—the frequency increases, the wavelength becomes shorter and more energy is transmitted. This continues, and the metal glows blue and eventually white. Incandescent light bulbs use a fine filament, typically tungsten wire, which an electrical current heats to 2700 K, above which point filament evaporation becomes excessive. The lamp is either evacuated, or filled with an inert gas, to prevent loss of tungsten from evaporation and to reduce the blackening of the inside of the glass bulb. At this temperature, the majority of radiation is emitted as heat in the infrared region of the EM spectrum, rather than as light, with the consequence that incandescent lamps tend to be rather inefficient converters of energy.

Figure 12.5 shows the relative irradiance of three different light sources, where irradiance is the total hemispherical radiant flux per unit area. Note the incandescent light curve predominantly in the infrared region of the spectrum. The diagram shows the spectral distribution of natural light (sunlight at sea level) compared with that of a typical incandescent lamp and of a standard 'cool white' fluorescent lamp.

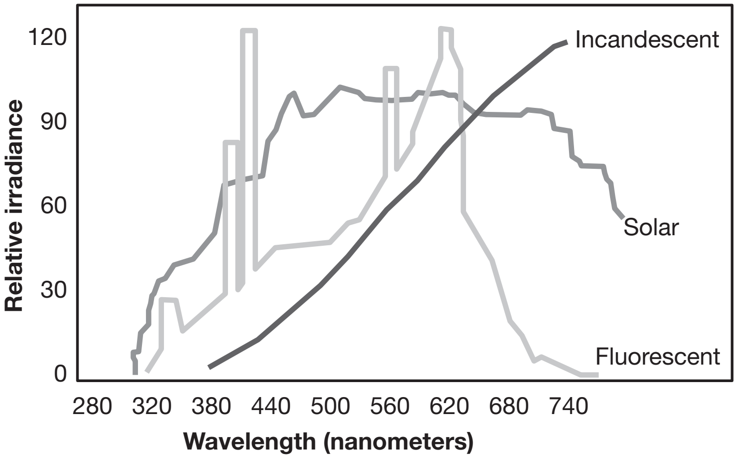


Figure 12.5 The spectral distribution of natural light compared with that of a typical incandescent lamp and of a standard 'cool white' fluorescent lamp

12.4.4.2 Fluorescent lamps

These are low pressure mercury lamps, available as hot cathode and cold cathode versions. The hot cathode is the type normally used in offices and workplaces; the cold cathode type is mainly used for signage and advertising. The central element in a fluorescent lamp is a sealed glass tube which contains a small quantity of mercury and an inert gas, typically argon, under very low pressure. The tube also contains a phosphor powder, coated along the inside of the glass. Different phosphors are selected for use in fluorescent tubes depending on the specific frequencies of the light they emit. When a current is passed, the mercury atoms become excited and emit UV radiation, which impacts upon the phosphors on the inside of the glass tube. The phosphors absorb the radiation, then re-emit it at a longer wavelength, within the visible spectrum.

Fluorescent lamps are much more efficient converters of electrical energy than incandescent lamps.

12.4.4.3 Electric discharge lamps

An alternative and more efficient form of lighting is achieved by passing an electric current through a gas, which excites atoms and molecules to emit radiation of a spectral distribution characteristic of the elements present. The most commonly used metals are mercury and sodium, as their characteristics emit useful visible radiation. Discharge lamps are often classified as high and low pressure. In a low pressure lamp with mercury or sodium vapour as an active ingredient, the metal vapour is mixed with an inert gas, often neon or argon. The vapour pressure of the metal is usually well under 1×10^{-3} atmospheric pressure. High pressure lamps are often referred to as high intensity discharge or HID lamps. HID lamps include the groups of electrical lights commonly known as mercury vapour, metal halide, high-pressure sodium, and xenon short-arc lamps. The light-producing element of these lamp types is a well-stabilised arc discharge contained within a refractory envelope (arc tube) with wall loading in excess of 3 W/cm^2 (19.4 W/in^2). Compared to fluorescent and incandescent lamps, HID lamps are highly efficient in that they produce a large quantity of light in a small package. HID lamps generate light by striking an electrical arc across tungsten electrodes housed inside a specially designed inner fused quartz or fused alumina tube which is filled with both gas and metals. The gas aids in the starting of the lamps. The metals produce the light once they are heated to a point of evaporation.

Typically, HID lamps are used when high levels of illumination are required for large areas, and when energy efficiency and/or light intensity are required. These areas include warehouses, gymnasiums, large public areas, outdoor activity areas, roadways, parking lots and pathways. More recently, HID lamps, especially metal halide, have been used in small retail and residential environments.

12.4.5 THE EYE AND VISION

The eye has two separate, but related, functions:

- It acts as an optical instrument to collect light waves from the environment and project them as images onto the retina.
- It is a sensory receptor which responds to the images formed on the retina by sending information by way of the visual nerve to the visual areas of the brain.

12.4.5.1 Vision

Light rays striking the eye first enter the cornea, which has a high degree of curvature and a refractive index of 1.33, compared to 1.00 for air. These two factors cause bending in the light rays as they enter the eye. (Water also has a refractive index of 1.33, which explains why the refractive power of the cornea is lost when swimming underwater.) The rays then pass through the lens of the eye, which has a refractive index of 1.39, and this causes further bending. As a result of this process, light rays are brought to a focus on the retina at the back of the eye.

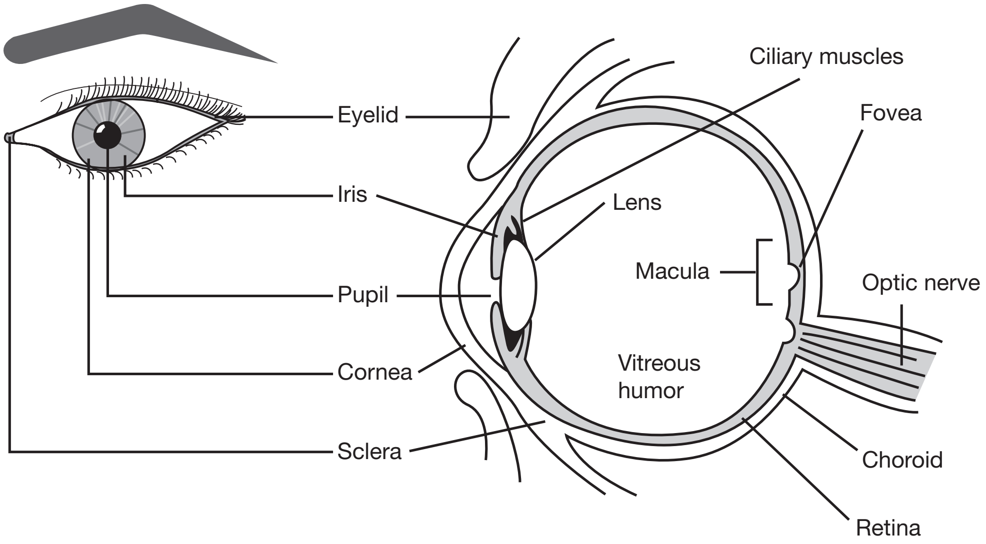


Figure 12.6 Illustration based upon information from National Eye Institute/National Institutes of Health

Accommodation is the process by which the refractive power of the eye is modified for viewing nearby objects. It is produced by a thickening of the lens. The lens is an elastic capsule, which is normally in a flattened shape, but when acted upon by the ring-shaped ciliary muscles which encircle it assumes a more spherical shape; this process is known as accommodation. The ciliary muscles are relaxed when the eye is focused on distant objects, hence the advice given to persons working at visual display units, or other tasks in the near visual field, that they should take regular breaks from their work and relax the eyes by focusing on distant objects, for example by gazing out of the window.

Where the light rays strike the retina, there are two sets of photoreceptor cells, called rods and cones (due to their shape). The cones are concerned with colour vision and fine detail, while the rods are much more sensitive to low levels of illumination than the cones, but have a lower level of visual acuity. Photopic vision is the term for the function performed by the cones, while scotopic vision is the term used to describe the function of the rods. The part of the retina termed the fovea is a region where only cones are found, and here they are particularly densely packed. This is the region of the highest visual acuity or most detailed vision, which is about 40 times that at the retinal border. The photoreceptor cells convert the light energy into nerve impulses, which are relayed along the optic nerve to the area of the brain which then forms the image.

12.4.5.2 The eye's response to differing light levels

The level of illumination has a critical effect on the ability of the eye to focus. At low light levels, the contrast is reduced and the sharpness of the image is diminished, making it more difficult to see. Focusing requires more effort when illumination is poor, especially in older workers.

The muscles of the iris control the size of the pupil, enlarging or reducing the opening to regulate the brightness of the image projected on the retina. Effort is needed only to change the size of the opening, rather than to maintain it. When the pupil reaches the required diameter, the muscles of the iris relax. For this reason, repeated viewing of objects that have different brightness levels is more tiring than viewing objects of uniform brightness (Aronoff & Kaplan 1995).

In many workplaces, a crucial aspect of safety is guarding against sudden changes from very bright to dimly lit areas or vice versa. Upon entering a dark room, the eye is unable to perceive anything initially; objects gradually become discernible with time, usually within 5 minutes. This is due to the initial rapid response by the cones in the retina, followed by the slower response of the rods. The rods eventually adapt to a greater degree, although this process may take as long as 25–30 minutes. This adaptation may continue slowly for several hours. In moving from dark to light, the reverse process occurs, with a temporary loss of vision occurring until the eyes adapt to the sudden increase in the level of illumination.

12.4.6 TERMS AND UNITS OF MEASUREMENT

The following terms, taken from AS/NZS 3665 *Simplified Definitions of Lighting Terms and Quantities* (Standards Australia 1989), should be noted:

- **Luminous flux** Symbol Φ, unit lumen (lm). Luminous flux is the quantity of the energy of the light emitted per second in all directions. One lumen is the luminous flux of the uniform point light source that has luminous intensity of 1 candela and is contained in 1 unit of solid angle (or 1 steradian). A solid angle can be regarded as a cone. This brings us to the concept of the solid angle, and its unit, the steradian. A solid angle can best be described as a measure for that portion of space about a point bounded by the surface of a cone whose top (vertex) is at the point. This concept is shown in Figure 12.9 for 1 m radius of the sphere. Since the surface area of the sphere is $4\pi r^2$ then the luminous flux of the point light source is 4π lm.
- **Luminous intensity** Symbol I, unit candela (cd). Luminous intensity is the concentration of luminous flux emitted in a specified direction. Luminous intensity is the ability to emit light into a given direction, or it is the luminous flux that is radiated by the light source in a given direction within the unit of the spatial angle. If the point light source emits Φ lm into a small spatial angle ß, the luminous intensity is $I = \Phi/ß$.

$$1 \text{ candela} = 1 \text{ lumen per steradian} \qquad \text{(Equation 12.6)}$$

- **Illuminance** Symbol E, unit lux (lx). Illuminance is the luminous flux density at a surface (luminous flux incident per unit area, lm/m^2). It describes the amount of light that covers a surface. If Φ is the luminous flux and S is the area of the given surface, then the illuminance E is determined by $E = \Phi/S$. One lux is the illuminance of 1 m^2 surface area uniformly illuminated by 1 lm of luminous flux. Figure 12.7 illustrates this definition. Table 12.5 shows the illuminance of different types of light.

Table 12.5 Table showing typical natural and artificial light levels

Environment	Lux
Typical bright sunny day in summer outside	100 000
Typical overcast sky in summer	20 000
Sunny winter day outside, temperate climate	10 000
Dull winter day	3000
Good workplace lighting	1000
Good street lighting	40
Full moon	0.25
Starlight	0.01

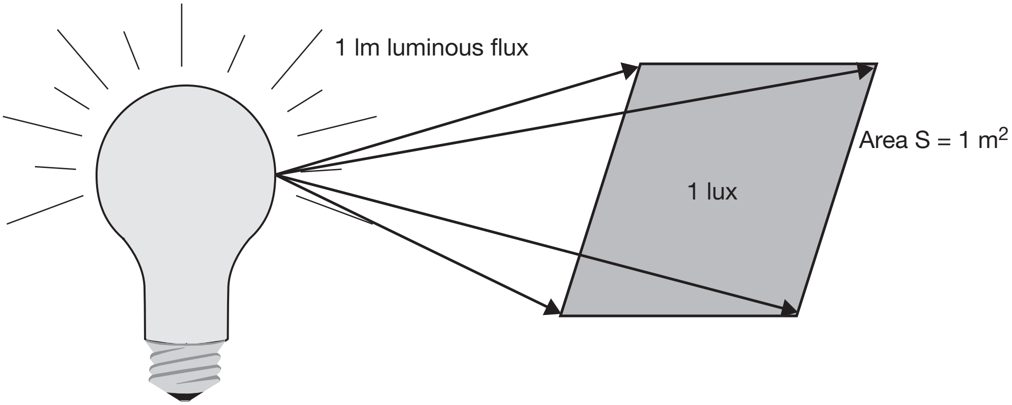


Figure 12.7 Diagram showing the relationship between lumen and lux

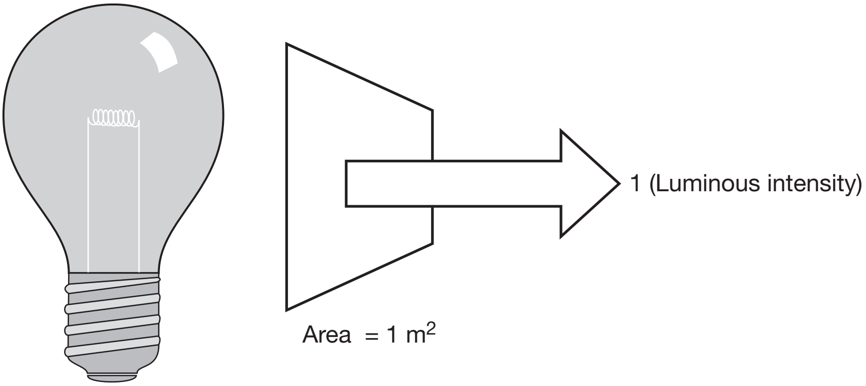


Figure 12.8 Luminance, the intensity of light emitted in a given direction by a unit area

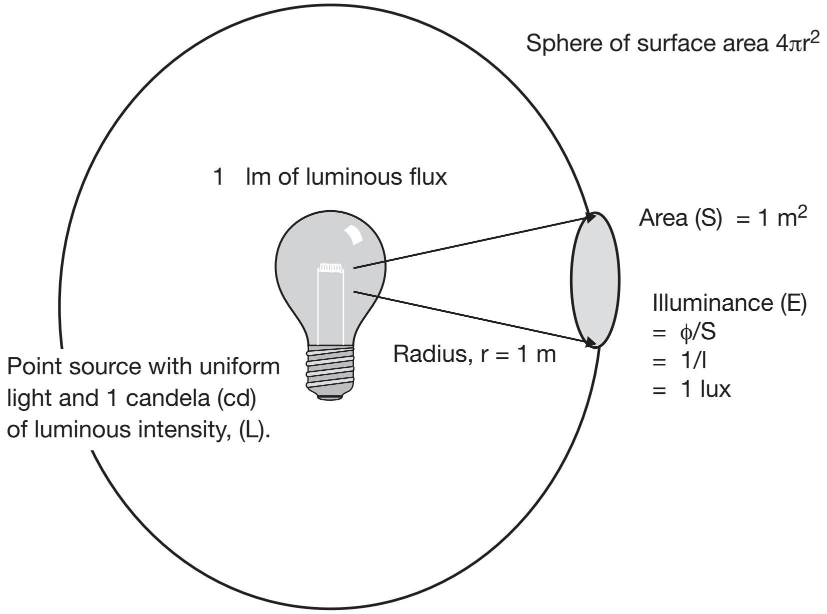


Figure 12.9 Diagram illustrating the relationship between luminous intensity, luminous flux and illuminance

- **Luminance** Symbol L. Luminance is the luminous intensity emitted by the surface area of 1 cm^2 (or 1 m^2) of the light source. Mathematically, L = I/S where I is the luminous intensity and S is the area of the source surface perpendicular to the given direction. The unit of luminance is cd/m^2 or cd/cm^2. Figure 12.8 shows the concept.

The relationships between luminance L, luminous flux Φ, and illuminance E, are shown in Figure 12.9.

The lumen is the photometric equivalent of the watt, weighted to match the eye response of the 'standard observer'. Yellowish green light (555 nm) receives the greatest weight because it stimulates the eye more than blue (450 nm) or red light (660 nm) of equal radiometric power. One watt at 555 nm = 683.0 lumens.

To put this into perspective: the human eye can detect a flux of about 10 photons per second at a wavelength of 555 nm. This corresponds to a radiant power of 3.58×10^{-18} W (or Joules/s). Similarly, the eye can detect a minimum flux of 214 and 126 photons per second at 450 and 650 nm, respectively.

Lighting design and evaluation are concerned with the light entering the eye, the surface being viewed (e.g. the work) and the source which provides the light. This is the lighting triangle as shown in Figure 12.10).

The distance from the eye to the surface, and the distance from the light source to the surface, are the critical factors. The distance from the light source to the surface (d) and the angle (θ) at which the light reaches the surface determine the amount of light received by the surface, or illuminance (E). The smaller the angle (θ) for any given light source of luminous intensity (I) and the smaller the distance (d), the higher the

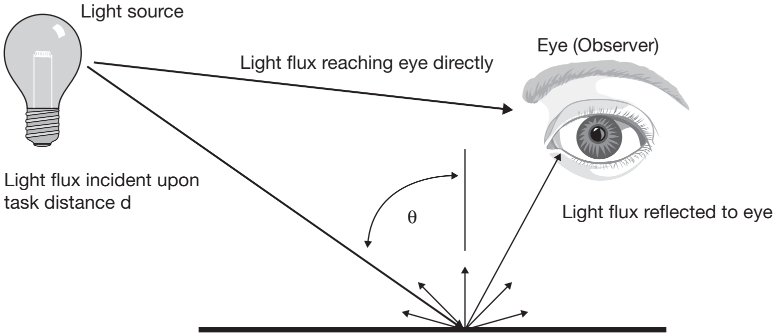


Figure 12.10 The lighting triangle
Source: Standards Australia (1989)

illuminance on the surface and the better the visibility of the task (Longmore 1980). Thus, the illuminance is described by the following relationship:

$$E = (I \cos \iota)/d2 \qquad \text{(Equation 12.7)}$$

12.4.7 MEASUREMENT OF LIGHT

Photometers are photoelectric instruments that use special optic filters to reconstruct the exact response of the human eye to light intensity. They consist of a photocell which converts light energy into an electric current. A light-measuring cell in the meter (photo diode) converts incident light into an electronic signal that is read and displayed as lux on the meter's LCD. In older instruments, this is connected to a moving coil meter, which displays the current as lux.

Ideally, the photometer (sometimes referred to as a lux meter, or even just light meter) should have a measurement range of 0.001–100 000 lux, although a range of 0.1–20 000 lux is acceptable for most workplace applications. The photocell should be connected to the meter by a cable, which ensures that the meter can be read without the user casting a shadow over the cell. The light sensor should also be colour corrected, in other words, its spectral responsiveness must be matched to that of the human eye. Instruments with spectral response correction filters to limit the sensitivity to UV and IR radiation, and cosine correction devices to ensure the correct evaluation of oblique light, are preferred. All meter types should be regularly calibrated for accuracy.

12.4.8 LIGHTING FOR THE WORKPLACE

The visual demands of the different tasks in the office will determine the lighting needed in the area. AS/NZS 1680.1 *Interior Lighting* (Standards Australia 1990) recommends the illumination levels for various types of office tasks, activities and interiors, as shown in Table 12.6.

Table 12.6 Recommended levels of illumination for particular applications

Class of task	Recommended maintenance illuminance (lux)	Characteristics of the activity and interior	Representative activities and interiors
Intermittent use	80	Interiors requiring intermittent use with visual tasks limited to movement and orientation	Staff change rooms
Simple	160	Occasional reading of clearly printed documents for short periods	Waiting rooms
Ordinary or moderately easy	240	Continuously occupied interiors where moderately easy visual tasks with high contrasts or large detail are required	Computer usage
Moderately difficult	400	Areas where visual tasks are moderately difficult with low contrasts	Routine office work; e.g. reception, reading, writing
Difficult	600	Area where visual tasks are difficult with low contrasts	Drawing offices; inspection tasks; proof reading
Very difficult	800	Areas where visual tasks are very difficult with very small detail	Fine inspection; colour matching of dyes
Extremely difficult	1600	Areas where visual tasks are exceptionally difficult with exceptionally small detail	Finished fabric inspection; assembly of minute mechanisms; jewellery and watch making

Source: Standards Australia (1990)

The lighting or illumination levels affect safety, task performance and the visual environment by revealing different elements of the interior to differing extents. Although a poor lighting environment can result in eyestrain or headaches, essentially lighting is a matter of ergonomics. For this reason, lighting is not a major health risk factor.

Figure 12.11 Diagram of a typical lightmeter, showing LED display (1), range switch (2), on/off switch (3) and the photocell (4)
Source: Diagram courtesy of T.P.S. Pty Ltd

Other relevant factors to consider in the visual environment include:

- avoidance of high light and deep shadows
- absence of direct glare from lamps, luminaires or windows
- an appropriate luminance distribution on interior surfaces
- use of suitable colours on the main interior surfaces (see below)
- control of flickering lights
- use of light sources with suitable colour characteristics.

In Australia and New Zealand, more specific recommendations for lighting of industrial tasks and processes are described in AS/NZS 1680.2.4 (Standards Australia 1997), and the reader is recommended to refer to this standard. Lighting for screen-based equipment (SBE) is a special case and is covered by AS/NZS 1680.2.2 *Interior Lighting, Part 2.2—Office and Screen-based Tasks* (Standards Australia 1994).

12.4.9 ERGONOMICS OF LIGHTING

The objective of good lighting design is to apply visual ergonomics to optimise the perception of visual information, provide conditions for an appropriate level of task performance, maintain safety and provide an acceptable level of visual comfort. Ergonomically designed lighting takes the factor of human capability into account and will generally result in improvement in productivity.

12.4.9.1 Characteristics of the task

Four major parameters influence the nature of visual information processed, and therefore a worker's performance in a visual sense:

- **task characteristics**—includes size of object, distance, texture, colour, contrast, motion and time factors
- **ability of the visual system**—ophthalmic abilities, age, adaptation, depth and colour perception
- **lighting characteristics**—lighting levels (illuminance), uniformity, glare and flicker
- **work space factors**—postural constraints, safety requirements, other physical constraints and psychological factors (Clarke 1989).

It is often possible to compensate for a defect in any one of the above factors by an enhancement in one or more of the others. An obvious consequence of this is that the application of visual ergonomics can increase the number of options available to provide an acceptable visual environment.

12.4.10 THE BIOLOGICAL EFFECTS OF LIGHT

Each of the effects of light upon mammalian tissue may be classified as direct or indirect, depending on whether its immediate cause is a photochemical reaction occurring within that tissue or a neuroendocrine signal generated by a photoreceptor (Wurtman 1967).

12.4.10.1 Direct effects of light

One of the best known direct effects of light is that of the stimulation of vitamin D synthesis in the skin and subcutaneous tissue by sunlight. Of course, sunlight can be harmful, especially in the mid-ultraviolet erythemal radiations (290–320 nm), which cause sunburn to appear within a few hours of exposure; and chronic exposure to sunlight for several hours per day over a period of some years can cause permanent changes in skin structure. In the epidermis, these changes include skin atrophy, the formation of keratin plaques and, in susceptible individuals, the appearance of squamous cell carcinomas (Wurtman 1975b).

Sunlight has been used by physicians in the treatment of herpes, psoriasis and hyperbilirubinaemia (jaundice). Treatment for the two former conditions entails the use of photosensitisers, while the latter involves direct illumination of the entire body in order to lower the level of plasma bilirubin.

Photosensitivity is an abnormally high reactivity in the skin or eyes to UV radiation or natural sunlight. It may be induced by ingestion or inhalation of, or skin contact with, certain substances known as photosensitisers. Symptoms will vary with the amount of UV radiation, type and amount of photosensitiser, skin type, and age and sex of the person exposed. Photosensitisation of the skin and eyes can be caused by exposure to specific industrial chemicals. The skin can be affected by dermal exposure or inhalation. The eyes can be affected by vapours, gases and other volatile materials. In certain occupations, the risk from exposure to particular photosensitising chemicals and solar UV radiation is severe. For example, exposure to tar and sunlight can cause precancerous and cancerous skin lesions. Exposure to coal tar fumes can cause simultaneous inflammation of the conjunctiva and cornea (NOHSC 1991).

12.4.10.2 Indirect effects of light

Indirect effects of light are those that are mediated by the perception of light by the eyes and include various metabolic, hormonal and organic functions. Hollwich et al. (1975) refer to this as the 'energetic' function of the eye. The light-dark cycle or *zeitgeiber* (literally, 'time-giver'), is a stimulus that 'sets' circadian rhythms. Furthermore, the free running period—in other words, the circadian rhythms that are not synchronised to environmental time cues and that oscillate on a cycle other than 24 hours—seems to be influenced by intensity of light. The free running period is longer than 24 hours in dim light and shorter in bright light (Aschoff 1965). (Most totally blind people have circadian rhythms that are free running.) Free running causes recurrent insomnia and daytime sleepiness when the circadian rhythms drift out of phase with the normal 24-hour cycle (Sack et al. 2000).

A few years ago it was demonstrated that exposure to high levels of bright light (i.e. 6000–12 000 lux) on at least half of a worker's night shifts over 3 months is effective in altering circadian rhythms (Budnick et al. 1995). Also, the effectiveness of light in setting a diurnal rhythm on body temperature in rats has been found to be a function of the colour of light, with green light (530 nm) being the most potent and red (660 nm) and ultraviolet (360 nm) the least (McGuire et al. 1973). This is not altogether surprising as this response follows the action spectra of the photoreceptors in the eye.

12.4.10.3 Implications for occupational health

From the above, it can be seen that workers whose health and wellbeing can be adversely affected by travelling over several time zones, such as travellers or commercial aircrew, may benefit from exposure to high levels of light to re-establish their circadian rhythms. Elsewhere (in the popular press) it has been suggested that melatonin tablets may be used to avoid the effects of jet lag. Based on experimental dosing of shift workers with melatonin (Folkard et al. 1993), it is possible that melatonin tablets could be made available to those workers who normally encounter difficulties with shift work.

As well as the circadian rhythms of melatonin, it appears that there are also circannual rhythms, with melatonin production following seasonal variations. Moreover, this has been linked to clinical variables in patients with depression (Wetterberg 1990). This is consistent with research by the US National Institute of Mental Health and the National Academy of Sciences on the way in which exposure to bright light can offset the negative effects of a type of depression known as seasonally affective disorder (SAD), which appears to affect a large number of adults who become depressed during the dark days of winter (Clarke 1989). In regions in the far northern hemisphere, this can be commonplace, although from a work perspective it would only be likely to be a problem for workers who are 'light deprived'.

It is evident that there is a coherent relationship between light and health in humans. For many workers, the majority of their waking hours are spent under artificial illumination which provides less than 10 per cent of the outdoor light under a shady tree on a sunny day (Clarke 1989). Furthermore, the spectral distribution of this illumination is very different to that of natural light. It follows that the level of activity of the pineal gland, and hence melatonin secretion, will be affected by this lighting regime. Given the role of melatonin in various neuroendocrine functions of the body, it is possible that prolonged exposure to artificial light and the concomitant lack of exposure to natural light may be a contributory factor to sick building syndrome (Stone 1992; Robertson et al. 1989). Workers have been shown to prefer more daylight than artificial light at their workstations (Coyne et al. 1992). From an occupational health perspective, the following points should be considered in relation to the design of a workplace:

- Buildings should be built so as to maximise the use of natural light.
- Individuals should be allowed control of their own lighting environment to meet their own requirements.
- All workers should have access to natural light at their workstation.
- Windows should allow full transmission of light.
- Workers should be encouraged to take 'light breaks' and get out of artificially lit environments during their lunch periods.
- Where artificial lighting must be used, preference should be given to use of 'daylight' tubes rather than 'warm white' or 'cool white' tubes.

12.4.10.4 Making full use of daylight

Natural lighting is most effective in improving illumination. Maximising use of daylight improves morale and reduces energy costs. Examine the workplace layout, material flow and workers' needs, then consider the following options on making effective use of daylight:

- Provide skylights, for example by replacing roof panels with translucent ones.
- Provide additional windows in the workplace, and:
  - place machines near windows
  - move work requiring more light near windows.
- Consider the following before planning and installing windows and skylights:
  - their height, width and position (more light is available when the window is placed high on a wall)
  - install shades, screens, louvres, canopies or curtains on the windows and skylights to protect the workplace from external heat and cold while taking advantage of the natural light
  - orient skylights and windows away from direct sunlight to obtain constant but less bright light.
- direct skylights and windows towards the sun if variations in levels of brightness throughout the day do not disturb workers
- avoid storage of flammable liquids in direct sunlight as the magnification of the sun's heat may lead to vaporisation of the liquid and increase the risk of fire.

This is a subject area in which there is much work to be done. Clarke (1989) states that research is moving towards the study of psychological and physiological activation from light and colour. Although it has long been considered that a strong correlation exists between lighting and how humans act and feel, there is still little hard scientific data to measure the relationship.

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13. Biological hazards

Denise Elson MAIOH

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13.1 INTRODUCTION

The recognition of biological hazards as a causative agent of workplace disease or illness undoubtedly preceded the industrial revolution. Even though there was no knowledge of the existence of micro-organisms per se, there was recognition that working with animals and growing crops could cause illness, and that animals such as rodents or insects could also cause disease. These naturally occurring biological and microbiological hazards, along with dust exposure from ancient mining, are recognised as being the oldest of occupational health hazards. With rapid population growth and population movements from rural to city life during the 18th and 19th centuries, the significance of biological hazards (or biohazards) in the workplace and domestic life became more prominent, though still largely unrecognised by the medical establishment of the times.

This chapter provides basic information on biological hazards that can be encountered in the workplace today, as well as information on how to recognise and/or quantify these hazards, assess the risk and develop appropriate controls. The term ‘biological hazard’ as used in this chapter refers to hazards of biological origin, and covers both living micro-organisms such as bacteria and viruses and non-living biological material such as dander from chickens and rats. The different types of micro-organisms will be covered, citing examples of illnesses and diseases relating to the occupational environment. In-depth discussion of biological hazards is outside the scope of this text, as correct identification and evaluation of these hazards needs to be undertaken by qualified microbiologists.

In addition, while illnesses such as colds and influenza can be contracted in the workplace from non-occupational sources such as colleagues, these are not discussed in this chapter. Transmission of the causative agents of these illnesses (e.g. influenza virus) is not workplace specific, but because people meet together and necessarily congregate in workplaces, the workplace serves as a centre for disease transmission. The H&S practitioner is referred to their local public health authority for information on these public health matters.

13.2 BIOLOGICAL HAZARDS IN THE WORKPLACE

As long as people are manipulating the environment to suit their own needs, it is probable that new diseases will arise in the workplace that are caused by bacteria, viruses or other biological agents. The emergence of legionnaires’ disease from the introduction of cooling towers for air-conditioning systems is one such example. Similarly there is now increased risk for healthcare workers potentially exposed to human immunodeficiency virus (HIV, leading to AIDS) and various strains of blood-transmitted hepatitis viruses due to increased rates of infection in the general population.

The areas in which the H&S practitioner will encounter biological hazards are broad. Some examples are:

- **Offices** Fungi in air-conditioning systems, cold and influenza viruses from colleagues, sick building syndrome (which is non-specific and can be caused by bacteria, viruses and allergens).
- **Hospitals** Hepatitis viruses (B, C and other types that continue to be discovered) and HIV from patients' blood and body fluids/tissues, patients' diseases transmitted by the respiratory route (e.g. tuberculosis).
- **Diagnostic and research laboratories** Various infections acquired from patient samples, particularly when samples are suspected to contain another similar disease agent (e.g. Q-fever when the patient has influenza-like symptoms). Infections can also be acquired from certain micro-organisms that can be readily transmitted via the respiratory route (e.g. *Brucella* bacteria that cause brucellosis).
- **Abattoirs** Q-fever from working with pregnant sheep.
- **Food manufacturing industry** *Salmonella* and *Shigella* bacteria can be found in contaminated food, causing diarrhoea.
- **Farms, animal research stations, veterinary laboratories** Diseases that affect both animals and humans, for example contagious ecthyma of sheep or orf (a viral infection), Newcastle disease from poultry (another viral infection), anthrax from cattle and other animals (a bacterial infection) and psittacosis and trachoma from birds (also bacterial infections).

However, H&S practitioners can contribute effectively to the provision of a healthy workplace by:

- being aware of the existence of biological hazards in various types of workplaces
- recognising work situations with a potential to contain biological hazards
- recognising that some health effects could be due to biological hazards and seeking specialist medical help and advice
- being able to implement basic controls to minimise the risk where necessary.

13.3 ROUTES OF EXPOSURE, MECHANISMS OF ACTION AND CONTROL MEASURES

Although the nature of biological hazards is totally different from inanimate hazards such as dusts, vapours and chemicals, a number of control solutions are remarkably similar. This is because the familiar routes of entry are involved (inhalation, ingestion and skin contact). Inhalation of airborne droplets of liquid (aerosols) containing infectious micro-organisms is the most common means of acquiring an infection, both in the workplace and socially. In the control of infectious diseases, emphasis is placed on air quality, specifically through the prevention of the transmission of these infectious aerosols.

The key difference between an inanimate hazard and animate biological hazards such as bacteria and viruses is that when the micro-organism gains a foothold in the host it can then start to multiply (grow) and so produce a disease. There will, however, be a very large difference between the number of organisms at the time the person is infected (small) compared to the number when the person is ill (very large). With an inanimate hazard the amount required to induce illness is in a sense fixed, and does not change during the course of the illness (e.g. the amount of cadmium to make a person sick is ingested and remains at this level).

The human body does have some defence mechanisms. Whether or not ill health occurs depends on the concentration (usually numbers of micro-organisms) to which the worker is exposed, the virulence (toxicity) of the micro-organism and the resistance of the individual. Medical treatment is often available and effective. The H&S practitioner should, nonetheless, pursue preventive methods to prevent infection/illness occurring, rather than relying on the worker's natural resistance or medical intervention.

13.4 TYPES OF MICRO-ORGANISMS

As the name implies, micro-organisms are the minute life forms that exist ubiquitously throughout all parts of our planet. Many assist in the life cycles of the higher life forms, including humans, in fixing nitrogen, breaking down proteinaceous and carbohydrate matter, producing gas, maturing cheese and many more functions. Individual micro-organisms are usually too small to be seen by the naked eye, measuring from nanometres (nm) in size for viruses to about 20 micrometres (µm) for single-cell protozoa. Only some of the helminthic, multi-segmented worms can be seen by the unaided eye, and they are not usually classified as micro-organisms.

The types of micro-organisms and similar life forms discussed in this chapter are:

- bacteria
- fungi
- viruses
- parasites (e.g. protozoa)
- prions.

13.4.1 BACTERIA

Bacteria are microscopic single-celled organisms, existing in various shapes and sizes. Figure 13.1a and b shows the two main types of bacterial forms: **rods**, which are rectangular and can be found in strings or spirals, depending on the type of bacteria, and **cocci**, which are circular and found singly or in clumps.

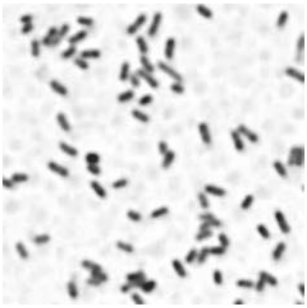

Figure 13.1a Rod-shaped bacteria

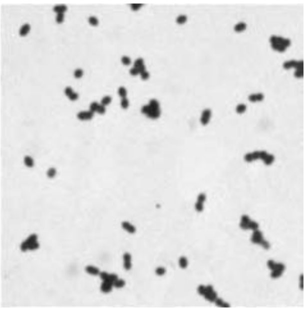

Figure 13.1b Cocci or circular bacteria

Some bacteria are useful; most do not cause disease in humans; others are pathogenic and are classified according to their degree of pathogenicity (severity of the disease they cause). Bacteria are noted for their asexual reproduction by division of the cell and do not need a host cell to survive. Disease-causing (pathogenic) bacteria usually infect specific target organs, and it is their replication that causes the disease.

Common workplace bacterial infections can occur through the skin, via neglect of cuts and abrasions. The most common causes are staphylococcal and streptococcal bacteria, but specific identification is done via a general practitioner and the H&S practitioner is not expected to have any expertise in this area. In the case of some bacteria, ill health results from toxins released from the cell rather than by mere invasion of the host by the bacteria. Examples of bacteria that release toxins are *Escherichia coli* and *Clostridium botulinum*. Where the worker is the agent of contamination (e.g. in food handling or hospitals), common bacteria of importance are *Salmonella* species, *Clostridium perfringens* and *Staphylococcus aureus* ('golden staph').

In some instances, a worker can be a carrier of disease without being aware of it (e.g. a food handler). Food can become contaminated and outbreaks of illness occur. This becomes a public health issue. Most important in this area are *Salmonella* bacteria. Similarly, in hospitals the increasing resistance of certain bacteria to antibiotics (e.g. *Staphylococcus aureus*) has led to infection of both patients and workers.

Another type of bacteria are the **rickettsiae**, which are smaller in size than most bacteria. Unlike other bacteria, they can only live or replicate inside a host cell, using some of the host cell's function. Rickettsiae were previously classified separately from bacteria, but this distinction is no longer formally recognised. Most rickettsiae can be spread only through the bite of infected insects (e.g. ticks, fleas) and are not spread through human contact. Typhus is one of the many diseases caused by rickettsiae—the bacteria responsible are *Rickettsia prowazekii*, which are transmitted to humans by head and body lice.

13.4.2 FUNGI

These agents, all chlorophyll free, cannot photosynthesise protein and other materials necessary for growth, so exist in parasitic form in living (or occasionally dead) cells. Fungal diseases are occupationally rare, usually affecting agricultural and outdoor workers (e.g. sporotrichosis caused by *Sporothrix schenkii*). Fungi may attack skin (e.g. tinea), lung tissue (leading to hypersensitivity pneumonitis or asthma-like symptoms) or become systemic throughout the body. One of the many causes of sick building syndrome (SBS) is the inhalation of fungal spores.

13.4.3 VIRUSES

The very small size of viruses renders them invisible to light microscopy, but they are visible under the electron microscope. Figure 13.2 shows influenza viruses as seen under an electron microscope, and illustrates one of the many shapes and sizes of viruses that exist.

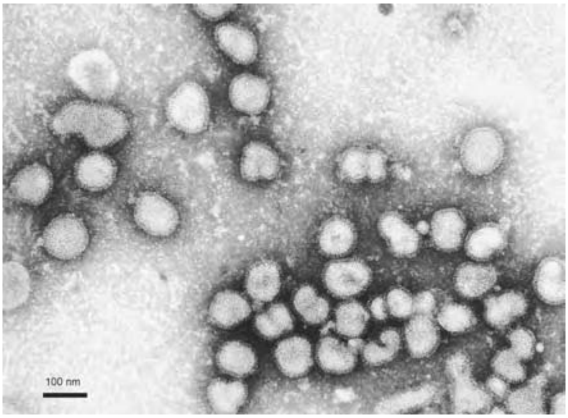

Figure 13.2 Influenza viruses

Viruses are not capable of independent living. They are made up of RNA (ribonucleic acid) or DNA (deoxyribonucleic acid) surrounded by a protein coat and are able to invade a living cell and subvert the cell's own replication program to reproduce more of the virus. Some viruses carry information that results in cancer production in host cells.

Occupational contact includes the following:

- respiratory viruses (e.g. influenza)
- zoonoses: animal viruses that are also infectious to humans (e.g. Nipah, rabies)
- arboviruses: viruses that are transmitted by insects (e.g. Ross River fever, dengue)
- viruses that may be transmitted in laboratories and hospitals through contact with human blood and body fluids (e.g. HIV, hepatitis B).

Examples of viral diseases well known in the non-occupational environment include measles, poliomyelitis, Ross River fever and chickenpox.

13.4.4 PARASITES

There is another range of disease-producing agents traditionally characterised as parasites. These range from small (e.g. protozoa, spirochaetes) to large and visible worms or flukes. Some protozoa have complicated life cycles, and may live in two or more hosts (e.g. malaria in man and the mosquito). Examples of larger parasites are liver flukes (trematodes), round worms (nematodes) and tapeworms (cestodes) that typically affect the alimentary canal, the blood or the liver. Those workgroups likely to be exposed to the vectors carrying the parasites (e.g. malaria-carrying mosquitoes) are generally in remote locations or crowded areas where hygiene and sanitation are inadequate.

13.4.5 PRIONS

Prions are unique in that they appear to be associated with at least one protein and contain no genetic material, and as such are not true micro-organisms. The pathogenic material is very resistant to inactivation by sterilisation or disinfection. The diseases caused by prions are Creutzfeldt-Jacob disease (CJD) of man, and bovine spongiform encephalopathy (BSE, or 'mad cow disease') of cattle, and scrapie of sheep and goats. BSE, scrapie and CJD are all termed transmissible spongiform encephalopathies (TSEs), which are diseases characterised by spongy degeneration of the brain with severe neurological consequences, and are usually fatal. CJD in humans occurs in a form associated with a hereditary predisposition (5% of cases) and a more common, sporadic form that accounts for 85–90 per cent of cases. The human form of BSE is known as variant CJD or vCJD, and was first reported in 1996 in the United Kingdom. At the time of writing, there have been no confirmed cases of vCJD or scrapie being transmitted to humans occupationally. Variant CJD has not been found in Australia and neither scrapie nor BSE has been found in Australian livestock.

13.5 CLASSIFICATION OF MICRO-ORGANISMS

Micro-organisms are categorised into different Risk Groups by AS/NZS 2243.3 *Safety in laboratories—Microbiological aspects and containment facilities* (Standards Australia 2002a), according to the risk they pose and the control procedures required to contain them.

13.5.1 RISK GROUP 1

'Low individual and community risk, a micro-organism that is unlikely to cause human or animal disease' (e.g. brewer's yeast).

13.5.2 RISK GROUP 2

'Moderate individual risk, limited community risk, a pathogen that can cause human or animal disease, but is unlikely to be a serious hazard to laboratory workers, the community, livestock, or the environment; laboratory exposures may cause infections, but effective treatment and preventive measures are available, and the risk of spread is limited.' Examples are *Staphylococcus aureus*, *Legionella* bacteria, hepatitis viruses and Ross River virus.

13.5.3 RISK GROUP 3

'High individual risk, limited community risk, a pathogen that usually causes serious human or animal disease and may present a serious hazard to laboratory workers. It could present a risk if spread in the community or the environment, but there are usually effective preventive measures or treatment.' Specialised training is required to work with these micro-organisms. Examples are *Brucella* bacteria, Hantaan viruses.

13.5.4 RISK GROUP 4

'High individual and community risk, a pathogen that usually produces life-threatening human or animal disease, represents a serious hazard to laboratory workers and is readily transmissible from one individual to another. Effective treatment and preventive measures are not usually available.' Specialised training is required to work with these micro-organisms. Examples are Hendra and Nipah viruses.

AS/NZS 2243.3 provides many examples of micro-organisms in each of the Risk Groups (except Risk Group 1, as these are too numerous). Microbiological laboratories are classified according to these risk groups: the micro-organisms in a particular Risk Group must be worked with in the corresponding Physical Containment (PC) Level laboratory. For example, Risk Group 2 organisms must be worked with in a PC2 (or higher) laboratory. Each PC level laboratory is constructed to a certain standard to be able to contain the infectious materials and protect workers and the environment.

The H&S practitioner in ordinary workplaces would not normally be expected to exercise any responsibility beyond Risk Group 2 micro-organisms, as extensive expertise and training are required in handling micro-organisms in Risk Groups 3 and 4.

13.6 SPECIFIC WORK ENVIRONMENTS AND DISEASES/ILLNESSES

Some workplaces will clearly represent a higher risk to workers, who may contract a disease or illness from micro-organisms. Workers handling animals, those in agriculture, and those in infectious disease research or pathology laboratories are obvious examples.

For a worker to become infected, the micro-organisms must enter the body. There are several routes of entry to be considered, including:

- inhalation when suspended in air or in water droplets (aerosols)
- ingestion in contaminated food or transmitted from hand to mouth
- through the skin, for example through cuts, scratches, bites (animals and insects)
- venereal transmission.

Some examples of occupational-related diseases are discussed below.

13.6.1 ZOONOSES: DISEASES TRANSMITTED FROM ANIMALS TO HUMANS

Many micro-organisms that cause disease in animals also cause disease in humans—these are termed zoonoses. These are obviously of concern to farmers, animal technicians, abattoir workers, researchers, veterinarians and other occupations where animals are handled. Some examples are:

Anthrax

This disease is normally rare in humans. It is caused by *Bacillus anthracis* bacteria. Sheep and cattle pick up the spore form of this bacteria from contaminated pasture. Workers at risk are those handling diseased animals or their hides, hair or offal (e.g. wool sorters, abattoir workers, farmers, veterinarians or stock handlers). In humans, spores may be transmitted through breaks in the skin, inhaled or ingested, giving rise to skin pustules, respiratory disease or enteritis respectively. The latter two conditions can be fatal. Infected animals must be destroyed and burned. Animal vaccines are available, and special vaccines are used for military personnel. Anthrax-causing bacteria have been used as a bioterrorist agent overseas, weaponised in the form of a white powder. In Australia so far, the 'white powder' incidents have been negative for anthrax spores.

Brucellosis

This disease is rare in humans. It is caused by various *Brucella* species which affect cattle, sheep, goats or pigs. *Brucella abortus* (cattle) no longer occurs in Australia, but formerly farmers, stockmen and veterinarians were at risk by (damaged) skin contact with infected animals. *Brucella suis* is most often seen in recreational pig shooters.

Leptospirosis

This disease is caused by the spiral-shaped bacteria *Leptospira interrogans* and is found in household pets, rats and mice. Humans contract the disease from infected animal urine or flesh, or contaminated water or soil, through the mucous membranes or abrasions. The severe form of this disease is known as Weil's disease. Occupations with a higher risk are farmers, veterinarians, abattoir workers and sugar cane and banana farmers. It is relatively rare in Australia compared to overseas, but can be found in warmer, wetter regions such as north-east New South Wales and Queensland.

Australian bat lyssavirus

This very rare infection has been seen in recent years in persons caring for injured fruit bats. The virus is very similar to rabies virus, hence the clinical features are also very similar (i.e. hydrophobia, bizarre behaviour, disorientation and hyperactivity). It is almost always fatal.

Q-fever

The micro-organism that causes this disease is *Coxiella burnetti*. This bacterium mainly affects those working in abattoirs killing sheep and feral goats, particularly pregnant animals. The bacteria are found in general dust, wool, straw and birth fluids, and may be inhaled. The primary infection may or may not show symptoms and manifests as an acute fever or pneumonia. The acute disease responds to antibiotic therapy and can be prevented by vaccination. Many abattoir workers, researchers and veterinarians are now vaccinated against Q-fever.

Psittacosis

The highly infectious bacterium *Chlamydia psittaci* that causes this disease is often harboured by parrots and budgerigars. Inhalation of this micro-organism causes fever, headache and pneumonia. Those keeping and handling parrots and budgerigars are at risk (e.g. pet shop or aviary owners).

13.6.2 HUMAN DISEASES

Shigellosis

Caused by *Shigella dysenteriae* bacteria. The health effects are dysentery, diarrhoea and malaise, and are typically found in children and institutionalised persons. Care staff may also be affected. Control is by personal hygiene measures to prevent faecal–oral (hand to mouth) transmission (i.e. ingestion of the micro-organisms).

Hepatitis

Hepatitis viruses are classified as types A, B, C and others still to be identified. Hepatitis A is associated with gastroenteritis and is transmitted through food and water that has been contaminated by sewage, and by human carriers. Hepatitis A can be contracted by sewerage workers, childcare staff and healthcare workers from faecal–oral transmission.

Hepatitis B and C and other hepatitis viruses are blood-borne. B is the most important in the work environment, particularly for those exposed to human blood and body fluids (e.g. ambulance staff, healthcare workers, first aid providers in the workplace, microbiologists in diagnostic laboratories, police, armed forces). Infection can result from needlestick injuries in the workplace, abraded skin contact with contaminated blood or splashes to the eyes and mouth. It causes fever, headache and jaundice. Some people may be carriers without showing symptoms and without knowing.

Immunisation against hepatitis A is recommended for sewerage workers and against hepatitis B for microbiologists working in diagnostic laboratories, healthcare workers and similar occupations. Advice should be sought from the latest version of the *Australian Immunisation Handbook* (DHA 2003).

Refer to AIDS (below) for information on minimisation of risk.

Ringworm

This is a general term for infections caused by several different fungi that affect skin, hair, fingernails (dermophytes) and result in itching, scaly skin or red patches. The most common is athlete's foot or *Tinea pedis*, which occurs in warm, moist areas such as showers. Contact with an infected person, or places where an infected person has been, can transmit the agent. Hence those who work in gymnasiums, laundry staff, veterinarians and athletes are at risk. Control is by using good personal hygiene, well-ventilated shower/change areas and high-temperature laundry washes.

Tuberculosis

This disease is currently on the increase due to increasing world travel. It is caused by *Mycobacterium tuberculosis* (also a bovine tuberculosis). There is also increasing concern with the emergence of multi-drug-resistant strains of the bacteria. In the past it affected miners and those in crowded conditions who were exposed to heat and dusts, but now healthcare staff are the main occupational group at risk. Inhalation is the main route of infection, but ingestion of infected meat or milk may also lead to infection. Symptoms may include fever, weight loss, cough and swollen neck (scrofulous).

Aspergillosis

This is a rare fungal disease resulting from inhalation of spores of *Aspergillus fumigatus* that may occur in large numbers in stored grain. Farm workers are most at risk.

Toxic organic dust syndrome

This is an illness that can affect farmers. Pig farmers are especially at risk of infection via the dust where pigs are raised indoors. It is similar to Farmer's lung (see Section 13.7.1), but is milder, short-lived and not an allergic reaction.

Legionnaires' disease

This disease is caused by the bacterium *Legionella pneumophila*. Symptoms include fever, chills, headache, pains and cough. This bacterium exists naturally in the environment, but favourable conditions may enable it to flourish and multiply rapidly in air-conditioning cooling systems, air humidifiers, recreational water facilities (spa pools), tepid water and some hot water showerheads, where it may enter the body by inhalation of a contaminated aerosol. Employers must ensure that conditions for rapid growth and dispersal of the bacteria are strictly controlled. State legislation sets down the requirements for the registration and maintenance of cooling towers, which includes advice on the wearing of PPE by maintenance workers. Details on maintenance and other aspects of microbial control can be found in AS/NZS 3666 *Parts 1–3* (Standards Australia 2000b; 2002d; 2002e). It should be noted that aerosols generated in the cooling tower cannot reach the recirculating air-conditioning system except by drift. Secondly, well-operated and regularly maintained cooling towers have not been associated with outbreaks of legionnaires' disease.

AIDS (Acquired Immuno Deficiency Syndrome)

As described above for hepatitis, certain workers such as healthcare workers, emergency workers, autopsy and mortuary workers, who have frequent contact with human blood and body fluids, have a risk of contracting AIDS from HIV (human immunodeficiency virus) that is significantly higher than that of the general workforce.

Numerous guidelines are available that proscribe the precautions that need to be taken to minimise the risk, including *Infection Control Guidelines for the Prevention of Transmission of Infectious Diseases in the Health Care Setting* (DHA 2004). In brief they are:

- treat all sharp instruments with extreme care to avoid potential injury; use alternatives wherever possible
- dispose of sharps directly into an impervious container without destruction, recapping, or dismantling by hand
- wear gloves, protective clothing, respiratory and eye protection if directly exposed to body fluids, secretions, wastes and mucous membranes of any person
- adopt a high level of personal hygiene if potentially exposed to human blood and body fluids.

Items that have been in contact with potentially contaminated blood must be chemically decontaminated. Expert advice should be sought on the correct method for decontamination (chlorine-based disinfectants are usually effective).

In the application of first aid in the workplace, disposal of contaminated blood and body fluids in toilet systems is acceptable. Sharp utensils ('sharps') and other disposable contaminated instruments must be disposed of in puncture-proof receptacles, by an approved method, or removed by a biological waste company.

Humidifier fever

Humidifier fever may be due to many different types of micro-organisms. It causes a range of symptoms such as respiratory irritation, wheezing and coughing, chills, headache, muscle aches, fever, irritation of nose and eyes, allergic alveolitis or respiratory hypersensitivity pneumonitis. It is not caused by *Legionella* bacteria.

It is a workplace illness that can affect workers in buildings with heating, ventilating air-conditioning (HVAC) or evaporative cooling systems, and particularly to poor system performance (ventilation). Occasionally, similar conditions can occur in buildings that have been subject to water penetration and have gone mouldy or in which stagnant water lies. Humidifier-related illness sometimes proves to be quite baffling and may demand close investigation. It has also been identified in the printing industry associated with spinning disc and spray-type humidifiers containing holding reservoirs.

The H&S practitioner can initially investigate symptoms, histories of illness, general air quality, the cleanliness of the air-handling system and associated ductwork. Consultant microbiologists are able to assist in determining the nature of the problem, using some of the air sampling methods described elsewhere.

Humidifer fever can be prevented by:

- provision of adequate drainage in water traps, cooling coils, in sumps, drain pans
- thorough cleaning and disinfecting (e.g. by hypochlorite) of evaporative cooling systems
- cleaning of ducts, filters, followed by decontamination
- cleaning of floors, walls and furniture with HEPA filtered vacuum system
- disinfecting and bleaching of floors.

Sick building syndrome (SBS)

This syndrome consists of a group of non-specific symptoms that are common in the general population and can include headache, blocked or runny nose, dry eyes and throat, and dry skin. It has become an issue since the advent of newer, more energy-efficient buildings that are more airtight and have air-conditioning systems. Indoor furnishings and equipment can produce particulates or gases that may affect some people. Surveys have shown that in more than 50 per cent of the buildings where people have had some or all of the symptoms described, there has been inadequate ventilation. SBS is covered in more depth in Chapter 9, Indoor Air Quality.

13.7 ALLERGIES

Certain materials of biological origin can cause allergic reactions in workers who come into contact with them. Their composition can vary, but the biological materials are often proteinaceous in nature, and can be secreted by micro-organisms (e.g. endotoxins), or be a component of larger organisms such as fungi. These hypersensitivities occur where the human body identifies foreign material and reacts to it, usually by an immunological reaction. The foreign materials are generally termed antigens or allergens when they elicit an allergic response. The body reacts to antigens by forming antibodies, which bind to the antigens and normally render the antigens harmless. Sometimes this binding process results in inflammation and tissue damage, that is, an allergic reaction. The lungs are particularly susceptible because they are exposed to large quantities of airborne substances that often cause allergic reactions, including dusts, pollens, fungi and chemicals. The body's response can range from usually mild rhinitis (hay fever) to more severe alveolitis and asthma.

Some examples of allergic reactions of occupational significance are discussed below.

13.7.1 FARMER'S LUNG AND MUSHROOM WORKER'S LUNG

These allergic reactions are caused by inhalation of spores of fungi such as *Micropolyspora faeni* and *Thermoactinomycetes vulgaris*, which can thrive in wet hay and grass. The spores are often found in large numbers in farmyard dusts and are released when hay or compost dusts are disturbed. Some, though not all, workers may respond by developing respiratory distress and asthma.

13.7.2 BAGASSOSIS

Spores of the mould *Thermoactinomycetes sacchari* can cause an allergic reaction in the lungs, causing breathing difficulties in some individuals working in the sugar cane industry. The mould is found in the bagasse (waste) from sugar cane that has been stored in damp conditions. Bagassosis is now rarely found in Australia.

13.7.3 LABORATORY ANIMAL ALLERGY

The condition is described in Section 13.13, Animal handling.

13.7.4 ENZYMES

Certain bacterial enzymes can provoke severe allergic reactions in some workers, particularly when inhaled. Only very small amounts are required to elicit an allergic response—for example, the NOHSC exposure standard for one such enzyme, subtilisin, is only 0.00006 mg/m^3. Subtilisin is the 'biological' component of some laundry detergents, and the workers at risk are those who prepare this product.

Another enzyme that can also cause allergies in workers during preparation is the enzyme papain, derived from papaya fruit and used as a meat tenderiser.

13.7.5 WOODWORKER'S LUNG AND OTHER ALLERGIC RESPONSES TO WOOD

Woodworker's lung is the term used to describe chronic respiratory effects from exposure to unspecified woods. There are also specific allergic responses to certain woods such as Western red cedar, which is a well-known cause of asthma and rhinitis. The Australian natives *Eucalyptus hemiphloia* (grey box) and *E. maculata* (spotted gum) both cause skin irritation, and various other woods can cause sensitisation dermatitis. Separate exposure standards exist for hardwood and softwood dusts, with both being sensitisers. Certain bacteria and fungi (particularly *Aspergillus* and *Penicillium*) on wood can cause organic dust toxic syndrome and other allergic reactions.

13.7.6 BYSSINOSIS

Byssinosis is a respiratory disease of workers in the cotton industry but is now rare in Australia with the use of dust minimisation procedures in cotton processing mills. The disease may be due to endotoxins secreted by micro-organisms that colonise cotton, as well as the dust itself.

13.8 PUBLIC HEALTH ISSUES

Certain micro-organisms (e.g. *Salmonella* bacteria) can cause disease in humans who consume food contaminated by the micro-organism. Contamination can occur when food handlers carry the bacteria but are asymptomatic—that is, they do not get the disease.

Similarly, humans can acquire disease from their recreational pursuits. Pig shooters, for example, can be infected by *Brucella suis* bacteria from handling wild pigs.

Parasites such as hookworms can live in the gut of humans. Hookworms are a round worm that is more prevalent in the tropics and can affect agricultural workers. Hookworm infestation causes gastrointestinal effects, iron deficiency and anaemia. Eggs are passed in human faeces, and the larvae develop in the soil and enter through the soles of feet in areas where sanitation is poor. Control involves hygiene and sanitation.

There have also been several instances of members of the public acquiring legionnaires' disease from breathing in aerosols emanating from cooling towers that are contaminated with large numbers of *Legionella* bacteria. Hence it is imperative that maintenance of all cooling towers is carried out as required by legislation.

For general workplaces, the risks due to HIV and hepatitis B and C viruses are low and the special precautions necessary for high risk workgroups such as health-care workers are not required. Most employers have programs in place to educate their workforce about these viruses and have a policy for prevention of transmission. Casual contact with infected persons will not result in transmission of the viruses.

13.9 CONTROL OF BIOLOGICAL HAZARDS IN THE WORKPLACE

Because of the known risk of contamination in many work situations, a number of very effective control measures have been established to permit safe working practices. These procedures are vital in workplaces such as:

- agriculture and animal handling facilities
- laboratories manipulating infectious micro-organisms
- hospitals, medical clinics and pathology laboratories
- diagnostic laboratories processing human and animal samples.

As micro-organisms are complex living entities, it has been difficult, if not impossible, to set exposure standards in the way that has been done for chemicals. In some instances, however, total bacterial counts (heterotrophic colony count or HCC) can be determined to indicate if there is a problem—this is done with the water in cooling towers. See Section 13.14 for more details.

13.9.1 CONTAINMENT OF MICRO-ORGANISMS

To prevent laboratory workers from infection (and also protect the environment), work with micro-organisms is classified into Risk Groups according to the degree of hazard posed by the micro-organisms (see Section 13.5), and must be carried out in laboratories built to specific containment requirements. AS/NZS 2243.3 (Standards Australia 2002a) specifies four Physical Containment (PC) Levels for laboratories, PC1–PC4. The Standard covers laboratory, animal, plant and invertebrate containment facilities.

The following summarises descriptions of each containment level of laboratory:

- **PC1** is a facility appropriate for student and undergraduate teaching laboratories, where work may be carried out on the open bench.
- **PC2** is the most common and is suitable for clinical, diagnostic, research and some teaching laboratories.
- **PC3** is required where work is carried out with micro-organisms that are a serious risk to humans and animals. The room or facility is kept under negative pressure to prevent the escape of hazardous micro-organisms.
- **PC4** is the highest level of containment facility and is used for work with micro-organisms that pose a life-threatening risk to humans. As for PC3, the room or facility is maintained at negative pressure, but full protective suits or similar need to be worn and full body showers must be taken prior to leaving the area.

13.9.2 CONTAINMENT WORK PRACTICES AND EQUIPMENT

Work practices that should be followed when dealing with micro-organisms are to be found in any good microbiological text (e.g. Madigan & Martinko 2006) or in AS/NZS 2243.3 (Standards Australia 2002a). These texts should be referred to for full details, but the following recommendations are general in nature and apply to all microbiological laboratories.

13.9.2.1 Aerosol suppression

Infectious aerosols are the most common cause of infections, with inhalation being the most significant route of entry into the body. Aerosols are formed whenever the surface of a liquid is broken, hence procedures must prevent or minimise infectious agents from becoming airborne as aerosols. This means preventing liquids such as blood from spraying, or preventing bubbles from forming and bursting.

13.9.2.2 Appropriate transport containers and labelling

Biologically hazardous materials, including human blood and body fluids (particularly when collected for medical or laboratory testing) must be treated as potentially infectious and held in secure containers and labelled with the biohazard symbol. All areas where biohazards and materials containing biohazards are handled should be labelled with the biohazard sign and appropriate PC level (Figure 13.3).

Figure 13.3
Sign for PC2 microbiological laboratories with biohazard symbol

13.9.2.3 Biological Safety Cabinets (BSCs)

These are special cabinets that allow operators to work with biological hazards that may become airborne and dispersed around the laboratory. Such cabinets are specially engineered and constructed to allow an operator located outside the cabinet to manipulate materials inside the cabinet. The airflows in the cabinet are such that the operator cannot be exposed to micro-organisms that become airborne, provided that the cabinet is used correctly. Air that is exhausted from the cabinet is filtered mechanically or electrostatically at a very high efficiency (around 99.99 per cent for micro-organisms).

Biological Safety Cabinets (BSCs) are available in Classes I, II and III:

- A **Class I BSC** is similar to a fume cupboard with a HEPA filter and provides operator protection, but no product protection (Standards Australia 2000a; 2002b).
- **Class II BSCs** (sometimes referred to as biohazard hoods) are the most commonly used types in laboratories and provide operator, product and environment protection (Standards Australia 2000a; 2004). See Figure 13.4 for a Class II BSC in use.

Figure 13.4
Laboratory worker using a Class II Biological Safety Cabinet

- A **Class III BSC** is a fully enclosed unit that is used for the highest risk agents (in PC3 and PC4 laboratories).

There are other cabinets for use in specific situations:

- **Cytotoxic drug safety cabinets**, for use with cytotoxic drugs (Standards Australia 1994; 2002c).
- **Laminar flow or clean bench cabinets**—these provide product protection only and must not be used where operator protection is required (Standards Australia 1989a; 1989b).
- **Pharmaceutical isolators**—these closed devices provide a clean working environment for the handling of materials which require protection from contamination or require containment for protection of personnel and of the background environment (Standards Australia 1999).
- **Fume cupboards** are designed exclusively for the protection of the operator when working with materials that may become airborne. They are commonly used for handling chemicals and should not be used for handling micro-organisms (Standards Australia 2001).

13.9.2.4 Prevention of needlestick injuries

Accidental needlestick injury was previously a common hazard for healthcare workers. If attempting to recap a needle after taking a blood sample from a patient, a worker can accidentally stick him/herself with the needle. Such injuries can cause disease if the needle is contaminated with micro-organisms such as hepatitis B virus and HIV. Hence the recapping of needles is no longer permitted and these items must be disposed of in approved impervious sharps bins, as specified in AS 4031 (Standards Australia 1992). The use of retractable-needle hypodermic syringes and similar devices can decrease the risk.

13.10 GENETIC MANIPULATION WORK

Manipulation of genetic material is carried out in many laboratories and this work is controlled by the Office of the Gene Technology Regulator (OGTR). Classification of micro-organisms and PC levels is the same as for microbiological laboratories, but they differ slightly in their requirements—refer to the latest versions of AS/NZS 2243.3 (Standards Australia 2002a) and the OGTR Handbook for details (OGTR 2001). While laboratory procedures are almost identical to those in AS/NZS 2243.3 (Standards Australia 2002a), the OGTR guidelines must be consulted.

13.11 TREATMENT OF INFECTIOUS WASTE

Facilities that generate or handle infectious waste require appropriate disposal methods so that no person subsequently handling the waste is exposed to potentially hazardous micro-organisms. The four methods commonly used are:

- **Sterilisation** This is a validated process used to render a product free from viable micro-organisms. It is usually achieved by the use of steam (in autoclaves or pressure steam sterilisers). Dry-air ovens and radiation can also be used. Sterilisation is used to treat infectious waste materials from laboratories, such as plastic waste, used gloves, sharps, diagnostic materials, cultures, infected animals, recyclable materials (e.g. glass) and diagnostic specimens. Prions can be destroyed using autoclaves, but longer cycle times at higher temperatures are required. Sterilisation is also used to treat clean recyclable materials such as glass bottles and scissors prior to reuse.
- **Disinfection** This is the use of chemicals such as formalin, glutaraldehyde and hypochlorite to kill a wide range of micro-organisms. Its use is usually confined to hard surfaces (e.g. laboratory benches, BSCs).
- **Decontamination** This is a physical or chemical process using, for example, formaldehyde gas, which kills or removes pathogenic micro-organisms, but it does not necessarily result in sterility.
- **Incineration** This is the complete destruction of micro-organisms by burning in a high temperature furnace. This is the ideal method of treating infectious waste, particularly infected sharps, but few incinerators are available with sufficiently high operating temperatures.

It should be emphasised that each of these techniques must be applied under strict conditions in order to ensure their efficacy. Times and temperatures are critical for heat treatments, even incineration, to kill all viable pathogenic micro-organisms. Penetration time is also critical—when using an autoclave, sufficient time must be allowed for the steam to enter the load within the autoclave. Chemical disinfectants must be at the correct strength (and freshly made up for some types) to kill all micro-organisms. Disinfectants do not act instantaneously—contact time is necessary to allow the disinfectant to have an effect, so a quick wipe of a bench top will generally be inadequate. As they can kill micro-organisms, chemical disinfectants are also hazardous to humans and must be used according to the relevant material safety data sheet (MSDS).

The use of gamma or ionising radiation for sterilisation is useful for materials which will be damaged by chemicals or heat or cannot be treated satisfactorily by other methods (e.g. some surgical materials). Ionising radiation has its own health hazards and therefore sterilisation using ionising radiation is usually carried out by specialised companies (e.g. Steritech in Melbourne). Mixtures of the gas ethylene oxide and a chlorofluorocarbon are used in hospitals for sterilising special surgical equipment that is heat sensitive.

13.12 WORK PRACTICES AND EMPLOYEE HEALTH PROGRAMS

In addition to containing or destroying micro-organisms, several other approaches are used in controlling the risk of infection or other disease from these agents. They include:

- administrative controls, which include pre-employment medical screening, regular physical and medical checks, temporary job reassignment for pregnant workers, and maintenance of medical records
- restricting access to approved workers where micro-organisms are manipulated
- standard work practices, which include prohibiting eating and drinking in the workplace, proper personal hygiene and disinfection procedures, using special protective clothing (PPE) which is not worn outside the workplace
- disinfection or decontamination on a programmed basis of all floors, equipment, safety cabinets, laboratory benches
- vaccination programs when working with certain infectious agents, for example hepatitis A and B viruses, bacteria causing tetanus, tuberculosis, Q-fever
- placarding with approved biohazard warning signs
- training of staff in the hazardous nature of micro-organisms, including safe handling and disposal procedures.

13.13 ANIMAL HANDLING

Additional care is required in work with deliberately infected animals, depending on the properties of the micro-organism used and whether or not it can cause disease in humans (zoonosis). It must be remembered that non-infected animals can also harbour diseases infectious to humans (e.g. pregnant sheep carrying Q-fever). Animal handlers should wear gloves at all times when feeding, watering or handling infected animals. Respiratory protection may also be required, depending on whether or not the micro-organism represents an inhalation risk.

Even when animals have not been infected, care should be taken to minimise the levels of dust, particularly when handling used animal bedding. Laboratory Animal Allergy (LAA) is common among animal workers, particularly those who work with small laboratory animals such as rats, mice and guinea pigs. Up to 35 per cent of workers can be affected, with some of these workers then developing asthma. The wearing of gloves and respiratory protection is recommended for all such workers. The urine of these small animals contains high concentrations of the proteins that cause the allergic reactions (termed allergens).

13.14 ASSESSING BIOLOGICAL HAZARDS IN THE GENERAL WORKPLACE

The H&S practitioner may be asked to determine if the workplace is causing illness because of contamination by micro-organisms. It is important to remember that micro-organisms are always present in the environment around us—it only becomes a problem if there are unacceptable numbers of pathogenic micro-organisms in the wrong place. Determining the nature and extent of the problem will ensure that appropriate controls can be implemented where necessary. The H&S practitioner can carry out sampling of the air in the workplace using equipment designed to capture bioaerosols (micro-organisms in the air), such as an impinger that captures bioaerosols into liquid, or a bioaerosol impactor. The testing may be required around ducts, pipework and other places where aerosols can be transmitted. Other simple methods are available for sampling surfaces for micro-organisms, such as surface swab kits and 'sticky' microscope slides. Figure 13.5 shows examples of equipment that can be used for these purposes.

Monitoring is undertaken for short periods only, given the need to capture and preserve viable (living) micro-organisms. In some workplaces, such as hospital environments and controlled atmosphere environments, personal sampling can be carried out to determine the exposure of individual staff to particular biological hazards such as fungi or bacteria (see Figure 13.6).

Figure 13.5 Equipment suitable for sampling bioaerosols

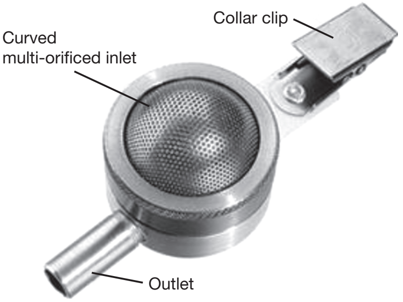

Figure 13.6 Equipment for personal monitoring of bioaerosol exposure

Where liquid samples need to be tested for micro-organisms (e.g. cooling tower water), dip-slides available as commercial kits are simple to use. The slides are coated with a growth medium and are dipped into the test liquid, removed and analysed. By using these simple kits, which are available commercially through air-conditioner service companies, regular testing can be carried out on air-conditioning cooling tower water.

All samples need to be sent to a microbiological laboratory where they are incubated in a special growth medium, followed by determination of the numbers and types of micro-organisms that have grown. The results will indicate if any remedial work needs to be done in the workplace.

13.15 REFERENCES

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14. Sources of information

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14.1 THE INFORMATION NEED

Unbiased and timely information is important to the H&S practitioner in addressing both health and hygiene issues in the workplace. Risk assessment, management and communication require well-informed judgment, and the need for objective information is particularly relevant for hazards that are not easily recognised or detected by our senses.

Since the mid-1990s, the principal modes of information retrieval and transfer have been the Internet, electronic resources and computer-mediated communication (Pisaniello & Brooks 1995a; 1995b; 1996). In many cases, the essential skills for H&S practitioners entail efficient electronic literature searching and critical appraisal of the information retrieved. Remember that workers and members of the public often have ready access to information, and the challenge for H&S practitioners is to 'add value' to hazard management and risk communication in the context of the particular workplace.

Use of the following information sources should provide the H&S practitioner with good basic coverage of the majority of workplace health and hygiene hazards.

It is important to bear in mind that the content and location (URL—Uniform Resource Locator, the unique address which identifies a resource on the Internet) of website information may change over time. Although the home pages of key government agencies tend to remain static, familiarity with Internet search engines such as Google is useful (Barker 2004).

14.2 CATEGORIES OF OH&S INFORMATION SOURCES

14.2.1 PRIMARY SOURCES

The 'gold standard' or primary sources of information come from what is called 'peer-reviewed' international scientific literature. These typically comprise occupational health and hygiene journals, and technical documents from recognised H&S professional societies, such as the Australian Institute of Occupational Hygienists Inc. (AIOH), and government agencies. The two most relevant occupational hygiene journals are the *Journal of Occupational and Environmental Hygiene* and the *Annals of Occupational Hygiene*. There may be articles describing original research or review articles, summarising the findings of a number of individual papers.

The important issue is the peer-review aspect, which means that experts have independently and anonymously reviewed the work and have recommended either acceptance or rejection of a manuscript sent to the journal editor.

Articles published in the peer-reviewed literature are often very technical, and so most H&S practitioners tend to read summary documents, with citations of the original published work.

14.2.2 SECONDARY SOURCES

The next most credible sources of information are those coming from state and federal government agencies, and recognised non-government organisations (NGOs) such as the World Health Organization, the International Labour Organization, the International Commission on Occupational Health, the International Agency for Research on Cancer and standards bodies such as Standards Australia. Documents may include codes of practice, guidance documents, toxicological summaries and criteria documents. Also included in this category are the major textbooks in OH&S (see Section 14.7).

14.2.3 OTHER SOURCES

There are many other potentially useful sources of information, especially those self-published on the Internet. However, caution should be used here, since self-published information may appear authoritative but actually represent a personal or organisational view, unsupported by scientific evidence.

H&S practitioners writing academic papers should avoid citing articles from newspapers and popular H&S journals and magazines that are not peer-reviewed. Specialised Internet search engines, such as Google Scholar, may assist in identifying scholarly literature across a broad range of sources. On the other hand, the popular literature may be useful for company policy development or review.

'Grey literature' (i.e. unpublished information) may also be valuable. It is often accessible via university or government H&S researchers. For example, unpublished reports of student research projects and consultancies may, subject to confidentiality constraints, provide a useful insight into the nature of a problem. The grey literature may also contain organisational program and policy documentation, useful for benchmarking, the development of internal procedures and so on.

The value of personal communication with recognised experts should not be understated. In the context of the Internet, this often takes place through email discussion groups or web forums.

Recent, and potentially relevant, Internet innovations are the 'wiki' (e.g. <www.wikipedia.org>) and 'blogs', such as one for confined spaces (<http://spewingforth.blogspot.com>). Again, caution should be applied in utilising this information in professional H&S practice.

In this regard, useful guides to evaluating Internet resources have been published by Johns Hopkins University (Kirk 1996) and the University of California, Berkeley (Barker 2004).

14.3 OH&S DATABASES

A particular strength of the Internet lies in its ability to store massive amounts of information on many networked computers. In recognition of the value of such information for workers and the community, a number of international government agencies have made the original information or bibliographic databases freely available.

Note that a bibliographic database has a search facility, but typically only includes the citation of the document (e.g. author, date, journal, etc.) or an abstract. A full text database includes all of the information in the document, and is often only available by paid subscription.

H&S practitioners may have access to databases by subscription at their workplaces, but should be aware of the free resources below.

14.3.1 BIBLIOGRAPHIC DATABASES

CISDOC
<www.ilo.org/dyn/cisdoc/index_html>
The CISDOC database, a product of the International Occupational Safety and Health Information Centre (CIS) of the International Labour Organization (ILO) in Geneva, contains references to key literature on safety and health at work.

Medline (free version is called PubMed)
<www.ncbi.nlm.nih.gov/entrez/query.fcgi>
A huge bibliographic database of the US National Library of Medicine (NLM).

NIOSHTIC–2
<outside.cdc.gov/niotic/>
A bibliographic database of all research reports supported in whole or in part by the US National Institute for Occupational Safety and Health.

14.3.2 FULL TEXT DATABASES

14.3.2.1 General

ILO Encyclopaedia
<www.ilo.org/encyclopaedia/>
A unique and widely respected reference. It has approximately 1000 articles and copious illustrations.

OSH Answers
<www.ccohs.ca/oshanswers/>
A database of commonly asked OH&S questions and answers, in plain language, maintained by the Canadian Centre for Occupational Health and Safety.

14.3.2.2 Legislation

AUSTLII
<www.austlii.edu.au/au/special/industrial/>
Australasian Legal Information Institute (Australian workplace relations subset).

LEGOSH
<www.ilo.org/public/english/protection/safework/cis/products/legosh.htm>
Consists of references to thousands of laws, regulations and international legal instruments dealing with OH&S matters in approximately 140 countries and international organisations.

14.3.2.3 Chemical and toxicological databases

Agency for Toxic Substances and Disease Registry (ATSDR)
<www.atsdr.cdc.gov/>
A US government agency website with comprehensive reports on a large number of chemicals.

Chemfinder
<www.chemfinder.com>
A partly free, partly commercial site. It is a good starting point for finding information on specific chemicals.

International Program on Chemical Safety—Inchem
<www.inchem.org/>
A means of rapid access to internationally peer-reviewed information on chemicals commonly used throughout the world. It consolidates information from a number of intergovernmental organisations.

International Program on Chemical Safety—Intox
<www.intox.org/>
Of interest to the hygienist is a databank of consolidated information on toxic agents and the management of toxic exposures.

MSDS databases
<www.ilpi.com/msds/> and <www.msds.com>
There are many MSDS databases now available via the Internet; they are more useful for pure chemicals than for mixtures (formulated products).

NIOSH Pocket Guide to Chemical Hazards
<www.cdc.gov/niosh/npg/npg.html>
The NPG is intended as a source of general industrial hygiene information on several hundred chemicals/classes for workers, employers, and occupational health professionals.

Toxnet
<http://toxnet.nlm.nih.gov/>
A cluster of databases on toxicology, hazardous chemicals, and related areas. Of particular value is the Hazardous Substances Databank.

14.3.2.4 Commercial products requiring subscription

CCOHS databases from the Canadian Centre for Occupational Health and Safety
<www.ccohs.ca>

- MSDS* (this database gives access to approximately 120 000 sheets from 600 North American manufacturers and suppliers).

- CHEMINFO (comprehensive, summarised OH&S information on chemicals. Produced by CCOHS H&S specialists, each chemical profile uses non-technical language to describe potential workplace hazards and control measures. 1300 chemicals).
- OSH References (OSHLINE, NIOSHTIC, NIOSHTIC–2, HSELINE, CISILO, Canadiana).
- CHEMpendium™ (CHEMINFO, CESARS, CHRIS, DSL/NDSL, HSDB, NJHS Fact Sheets, NIOSH Pocket Guide, Transport TDG, Transport 49CFR).
- Canadian enviroOSH Legislation plus Standards.
- RTECS® Registry of Toxic Effects of Chemical Substances (RTECS® is a definitive toxicological database with supplemental information pertinent to both the chemical industry and the OH&S community).

Chem Alert
<www.chemalert.com>
A chemical management software system: Chem Alert 2 provides tens of thousands of scanned manufacturers' original MSDSs.

Chemwatch
<www.chemwatch.net>
Chemgold MSDS database and Galleria Chemica, 500 separate global chemical databases.

HSELine
<www.hse.gov.uk/infoserv/hseline.htm>
A bibliographic database from the UK Health and Safety Executive. It contains over 200 000 references to worldwide information covering all aspects of occupational safety and health, and approximately 2000 additions are made each year.

Infosafe
<www.acohs.com.au>
An advanced database computer system for MSDS management.

Micromedex TOMES® plus
<www.micromedex.com/products/tomesplus/>
MEDITEXT, HAZARDTEXT, OHM/TADS (Oil and Hazardous Materials/Technical Assistance Data System), IRIS (Integrated Risk Information Systems), HSDB, CHRIS (Chemical Hazard Response Information System), New Jersey Fact Sheets, ERG 2000 (Emergency Response Guidebook).

OSH Update
<www.oshupdate.com>
An Internet service which contains ten bibliographic databases from worldwide authoritative sources.

OSH-ROM®
From <www.ovid.com>
This product is marketed by Wolters Kluwer (Croner) and contains CISDOC, HSELINE, MHIDAS, RILOSH, NIOSHTIC–2, OSHLINE and MEDLINE OEM.

14.4 ELECTRONIC RESOURCES

There are many Internet resources relevant to occupational hygiene, including tools for converting measurement units, calculating and illustrating composite measures such as WBGT, chemical reactivity guides, clothing and glove selection guides, etcetera.

H&S practitioners may find the following resources of general interest.

14.4.1 E-LEARNING RESOURCES

Case studies in Environmental Medicine
<www.atsdr.cdc.gov/HEC/CSEM/>
These case studies are oriented towards continuing education of medical practitioners, but are also of interest to occupational hygienists.

Safetyline Institute
<www.safetyline.wa.gov.au/institute/defaultnew.asp>
An online education and training facility established by WorkSafe Western Australia. The material includes basic occupational hygiene concepts and may be useful for refreshing knowledge. Enrolling in the Institute for general interest study is free. There are self-assessment tests associated with every lecture.

Toxicology Tutorials
<http://sis.nlm.nih.gov/enviro/toxtutor.html>
These tutorials cover basic principles, toxicokinetics and cellular toxicology.

The e-learning field is rapidly expanding and will be an important domain for both specialists (e.g. maintenance of professional certification) and those who need basic, general or hazard-specific OH&S training, such as secondary school students entering the workforce. Many H&S practitioners will be involved in developing such resources.

14.4.2 OTHER ELECTRONIC RESOURCES

I-BEAM
<www.epa.gov/iaq/largebldgs/ibeam_page.htm>
The Indoor Air Quality Building Education and Assessment guidance (I-BEAM) was designed by the US Environment Protection Agency to be used by building professionals and others interested in indoor air quality in commercial buildings. Inter alia, this comprehensive resource provides useful IAQ management tools and interactive illustrations of IAQ problem situations.

Safety Graphics, Posters and Microsoft Powerpoint™ presentations
<http://siri.uvm.edu> or <www.hazard.com/>
Provided as a free resource from the University of Vermont; the Powerpoint™ materials should be used with some caution as they are not peer-reviewed.

14.5 KEY INTERNET WEBSITES

14.5.1 GOVERNMENT AGENCIES

Australian Safety and Compensation Council (formerly the National Occupational Health and Safety Commission and Worksafe Australia)
<www.ascc.gov.au>
This is the key Australian web portal for national model regulations, standards, codes of practice, guidance documents, regulatory impact statements, hazard alerts, research reports and reviews, research and statistics databases (e.g. the national worker's compensation statistics database) and directories. It includes the Hazardous Substances Information System (HSIS). The HSIS is an Internet database that allows you to find information on hazardous substances that have been classified in accordance with the Approved Criteria for Classifying Hazardous Substances and/or have national exposure standards.

The HSIS provides access to two data sets, one for hazardous substance information and the other for exposure standard information. The data for substances that are common to both sets are linked. Both data sets can be searched using a range of search criteria. Search results (including the full data sets) can be printed or saved electronically.

As the national OH&S agency, the ASCC has website links to state and territory government agencies and statutory bodies as well as to international organisations.

New Zealand OH&S agencies
The Occupational Safety and Health Service, NZ Department of Labour, <www.osh.dol.govt.nz/index.htm> and the National Occupational Health and Safety Advisory Committee (NOHSAC) <www.nohsac.govt.nz/> are major providers of OH&S information.

United Kingdom Health and Safety Executive
<www.hse.gov.uk/>
Much of Australian OH&S legislation has been modelled on the UK system, thus the Health and Safety Executive website is often of interest to Australian practitioners.

United States National Institute for Occupational Safety and Health
<www.cdc.gov/niosh>
NIOSH is a major provider of OH&S information. It publishes information on a wide variety of topics, as well as hazard alerts, health hazard evaluation reports, and the Manual of Analytical Methods for laboratory analysis of chemical contaminants.

United States Occupational Safety and Health Administration
<www.osha.gov/>
OSHA is the US federal regulatory body, and the website is a key source of information on standards and regulations. It also includes a range of e-resources including industry-specific e-tools and presentations.

United States Mine Safety and Health Administration
<www.msha.gov>
As the name suggests, this site has a focus on H&S in mining. It features a range of videos (as streaming media), and other useful training resources.

Canadian Centre for Occupational Health and Safety
<www.ccohs.ca>
The CCOHS is the principal provider of OH&S information in Canada, and also a major international provider. The website has a useful peer-reviewed 'OSH Answers' section, giving basic information on a vast array of topics.

14.5.2 INTERNATIONAL AGENCY SITES

The following websites often provide useful guidance material and reports relevant to occupational hygiene. Some of the basic materials have been designed for developing countries.

European Agency for Safety and Health at Work
<http://europe.osha.eu.int/>

International Agency for Research on Cancer
<www.iarc.fr/>

International Labour Organization
<www.ilo.org/public/english/protection/safework/>

World Health Organization
<www.who.int/occupational_health/en/>

14.5.3 OCCUPATIONAL HYGIENE PROFESSIONAL ASSOCIATIONS

The Australian Institute of Occupational Hygienists Inc.
<www.aioh.org.au>
This website provides information about the professional practice of occupational hygiene in Australia, and a list of consultant members and committees. The Institute also distributes electronic and hardcopy conference proceedings and technical publications.

International Occupational Hygiene Association
<www.ioha.net/>
The IOHA represents the occupational hygiene profession on an international basis.

The British Occupational Hygiene Society
<www.bohs.org/>

American Industrial Hygiene Association
<www.aiha.org/>

American Conference of Governmental Industrial Hygienists
<www.acgih.org>

New Zealand Occupational Hygiene Society
<www.nzohs.org.nz/>

14.6 EMAIL LISTS AND ELECTRONIC NEWSLETTERS

UK Occupational Hygiene List
<www.mailtalk.ac.uk/lists/ukoh.html>

Global Occupational Hygiene Group
<http://health.groups.yahoo.com/group/globalocchyg-list/>

Occupational and Environmental Medicine List (Duke University)
<http://occ-env-med.mc.duke.edu/oem/occ-env-.htm>

OSHmail
<http://agency.osha.eu.int/oshmail/>
The electronic newsletter of the European Agency for Safety and Health.

CCOHS News
<www.ccohs.ca/resources/communications/mailinglists/CCOHS-NEWS.html>

US NIOSH eNews
<www.cdc.gov/niosh/enews/enewsV3N1.html>
The monthly newsletter of the National Institute for Occupational Safety and Health.

Advancing National Safety
<www.ascc.gov.au/NewsAndWhatsNew/Safety_Newsletters/default.asp>
The newsletter of the Australian Safety and Compensation Council.

14.7 TEXTBOOKS

14.7.1 OH&S AND THE INTERNET

In the mid-1990s a series of books on how to use the Internet emerged, with some dealing specifically with the OH&S area. Coinciding with a greater public and professional awareness of the Internet, there is now less demand for such books. A relatively recent example is the book by Stuart and Moore (1998).

14.7.2 GENERAL OCCUPATIONAL HYGIENE TEXTBOOKS

The following list refers only to books providing general coverage or dealing with basic principles.

Burgess, W.A. (1995) *Recognition of Health Hazards in Industry: A Review of Materials and Processes*, 2nd edn, John Wiley & Sons, New York.

DiNardi, S.R. (ed.) (2003) *The Occupational Environment: Its Evaluation, Control and Management*, 2nd edn, American Industrial Hygiene Association, Fairfax, VA. Includes CD.

Harris, R.L. (ed.) (2000) *Patty's Industrial Hygiene*: *Guide to Principles and Practice of Industrial Hygiene and Hazard Evaluation and Control*, 5th edn, John Wiley & Sons Inc., New York.

Perkins, J. and Rose, V.E. (eds) (1987) *Case Studies in Industrial Hygiene*, Wiley-Interscience, New York.

Perkins, J.L. (1997) *Modern Industrial Hygiene, Vol. I: Recognition and Evaluation of Chemical Agents*, Van Nostrand Reinhold, New York.

Perkins, J.L. (ed.) (2003) *Modern Industrial Hygiene, Vol. 2: Biological Aspects,* Van Nostrand Reinhold, New York.

Plog, B.A. and Quinlan, P.J. (eds) (2002) *Fundamentals of Industrial Hygiene*, 5th edn, National Safety Council, Chicago, IL.

Tranter, M. (2004) *Occupational Hygiene and Risk Management*, 2nd edn, Allen & Unwin, Sydney.

14.7.3 OTHER USEFUL OCCUPATIONAL HYGIENE BOOKS

DiNardi, S.R. (1995) *Calculation Methods for Industrial Hygiene*, Van Nostrand Reinhold, New York.

DiNardi, S.R. and Luttrell, W.E. (2000) *Glossary of Occupational Hygiene Terms*, American Industrial Hygiene Association, Fairfax, VA.

Finucane, E.W. (1998) *Definitions, Conversions and Calculations for Occupational Safety and Health Professionals*, 2nd edn, CRC Press, Boca Raton, FL.

Stern, M.B. and Mansdorf, S.Z. (eds) (1999) *Applications and Computational Elements of Industrial Hygiene*, CRC Press, Boca Raton, FL.

Stewart, J.H., Herrick, R., Horowitz, M., Labato, F. and Shapiro, J. (2005) *Industrial-Occupational Hygiene Calculations*, 2nd edn, Millenium Associates.

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Kirk, E. (1996) *Evaluating Information Found on the Internet*, Johns Hopkins University, Baltimore, <www.library.jhu.edu/researchhelp/general/evaluating>.

Pisaniello, D.L. and Brooks, B. (1995a) 'The Internet and OHS: Part 1: Overview and user's perspective', *Journal of Occupational Health and Safety—Australia NZ* 11:467–70.

—— (1995b) 'The Internet and OHS: Part 2: OHS-related Internet Tools and Resources', *Journal of Occupational Health and Safety—Australia NZ* 11:601–6.

—— (1996) 'The Internet and OHS: Part 3: Networking the Global OHS community', *Journal of Occupational Health and Safety—Australia NZ* 12:25–30.

Stuart, R.B. and Moore, C. (1999) *Safety and Health on the Internet*, 3rd edn, Government Institutes, Rockville MD.

Abbreviations

(Not necessarily limited to these entries)

ABCB	Australian Building Codes Board
AC	asbestos-cement
ACGIH®	American Conference of Governmental Industrial Hygienists
ACM	asbestos-containing materials
ACPSEM	Australasian College of Physical Scientists and Engineers in Medicine
AIOH	Australian Institute of Occupational Hygienists
ALI	annual limit of intake
ANSTO	Australian Nuclear Science and Technology Organisation
ARPANSA	Australasian Radiation Protection and Nuclear Safety Agency
ARPS	Australian Radiation Protection Society
AS/NZS	Australian/New Zealand Standard
ASCC	Australian Safety and Compensation Council
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BCA	Building Code of Australia
BCIRA	British Cast Iron Research Association
BEI®	biological exposure index
BET	basic effective temperature
BMI	body mass index
BMRC	British Medical Research Council
Bq	becquerel
BZ	breathing zone
C/kg	Coulomb per kilogram
cd	candela
CFD	computational fluid dynamics
CFU	colony forming units
CWP	coal workers pneumoconiosis
D	absorbed dose
DAD	digital audio dosimeter

dB	decibel
dB(A)	decibel measured on the A-weighting scale
Der p1	Dermatophagoides pteronyssinus (one species of house dust mite) allergen p1
DHA	Department of Health and Ageing
E	illuminance
EDTA	ethylenediaminetetraacetic acid
E_{eff}	effective irradiance
ELF	extremely low frequency
EM	electromagnetic
ES	exposure standard
ES-TWA	exposure standard, time weighted average
ETS	environmental tobacco smoke
eV	electron-volt
FPM	fluorescent particulate matter (a measure of ETS)
G	Giga (10^9)
Gy	Gray
HEPA	high efficiency particulate air filters
HID	high intensity discharge
HSE	Health and Safety Executive (United Kingdom)
HVAC	heating, ventilation and air-conditioning
Hz	Hertz
IAQ	indoor air quality
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionising Radiation Protection
ICRP	International Commission on Radiological Protection
IDLH	immediately dangerous to life or health
IOM	Institute of Occupational Medicine
IR	infrared
ISO	International Standards Organization
J	Joule
K	Kelvin
kW	kilowatt
L	litre
L	luminance
LCD	liquid crystal display
LEV	local exhaust ventilation
Lm	lumen
lx	lux
m	metre
MDI	methylenebisphenylisocyanate
mg/m^3	milligrams (10^{-3} gm) per cubic metre
MIRAN®	miniature infrared analyser
ml	millilitre (10^{-3} litre)

MRI	magnetic resonance imaging
μ	micro-, 10^{-6} as in micrometre
μg	microgram (10^{-6} gram)
m/s	metres per second
NaCl	sodium chloride
NATA	National Association of Testing Authorities
NES	national exposure standard
NHMRC	National Health and Medical Research Council
NIHL	noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre (10^{-9} metre)
NOHSC	National Occupational Health and Safety Commission
NORM	naturally-occurring radioactive material
NTP	normal temperature and pressure
OH&S	occupational health and safety
Pa	Pascal
PAH	polycyclic aromatic hydrocarbon
PAPR	powered air-purifying respirator
PHS	predicted heat strain
PID	photo-ionisation detector
PLM	polarised light microscope
$PM_{2.5}$	particulate mass with an aerodynamic equivalent diameter cutpoint of 2.5 mm
PM_{10}	particulate mass with a median aerodynamic equivalent diameter cutpoint of 10 mm
PMF	progressive massive fibrosis
PPE	personal protective equipment
ppb	parts per billion (1 in 10^9)
ppm	parts per million (1 in 10^6)
PTFE	polytetrafluoroethylene
PVC	polyvinylchloride
QFD	quartz fibre dosimeter
R	Roentgen
RH	relative humidity
RPE	respiratory protection equipment
RPM	respirable particulate matter
s	second (time)
SAD	seasonally affective disorder
SBE	screen-based equipment
SBS	sick building syndrome
SCBA	self-contained breathing apparatus
SEM	scanning electron microscope
SIMPED	Safety in Mines Research Establishment
SMF	synthetic mineral fibres
STEL	short term exposure limit

Sv	Sievert
T	temperature
Ta	air temperature
TEM	transmission electron microscope
Tg	globe temperature
TLD	thermoluminescent dosimeter
TLV®	threshold limit value
TNT	trinitrotoluene
Tnwb	natural wet bulb temperature
TVOC	total (aggregation of) VOCs in a mixture
TWA	time weighted average
TWL	thermal work limit
UKAEA	United Kingdom Atomic Energy Association
UV	ultraviolet
UVPM	ultraviolet particulate matter (a measure of ETS)
VOC	volatile organic compound
W	Watt (equivalent to J/sec)
WES	workplace exposure standard
WHO	World Health Organization
WBGT	wet bulb globe temperature
Φ	luminous flux
ω_R	radiation weighting factor
ω_T	tissue weighting factor

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