Plant Design and Operations

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CHAPTER

Operations

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CHAPTER OUTLINE

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INTRODUCTION

The purpose of this book is to provide practical guidance on issues to do with the design, operation and maintenance of process facilities, including chemical plants, oil refineries, offshore facilities and pipelines—with a focus on safety issues. It is organized into the following chapters:

Chapter 1 Operations
Chapter 2 Maintenance and Inspection
Chapter 3 Energy Control Procedures
Chapter 4 Occupational Safety
Chapter 5 Chemicals
Chapter 6 Personal Protective Equipment
Chapter 7 Health and Industrial Hygiene
Chapter 8 Human Factors and Ergonomics
Chapter 9 Firefighting
Chapter 10 Safety in Design
Chapter 11 Siting and Layout
Chapter 12 Equipment
Chapter 13 Piping and Valves
Chapter 14 Safety Instrumentation
Chapter 15 Transportation
Chapter 16 Security
Chapter 17 Common Hazards

This book is one in a series to do with the management of process facilities, both onshore and offshore. Other titles include *Process Risk and Reliability*

Management (*PRRM*) and *Offshore Safety Management.* There is a particularly strong overlap between the contents of this book and those of *PRRM* which discusses the process safety management systems that lie behind much of what is written here. For example, this book's Chapter 9 (Firefighting) is tightly integrated with Chapter 12 (Emergency Management) of *PRRM.* Another example is to do with the topic of Inherent Safety, the principles of which are discussed in *PRRM.* This book shows how those principles are applied to design of equipment such as pressure safety relief valves, tanks, and stairways.

The table of contents for *PRRM* is shown as follows:

Chapter 1—Risk Management
Chapter 2—Compliance and Standards
Chapter 3—Culture and Participation
Chapter 4—Technical Information
Chapter 5—Hazard Identification
Chapter 6—Operating Procedures
Chapter 7—Training and Competence
Chapter 8—Prestartup Reviews
Chapter 9—Asset Integrity
Chapter 10—Management of Change
Chapter 11—Incident Investigation and Root Cause Analysis
Chapter 12—Emergency Management
Chapter 13—Audits and Assessments
Chapter 14—Consequence Analysis
Chapter 15—Frequency Analysis
Chapter 16—Reliability, Availability, and Maintainability
Chapter 17—Managing a Risk Program
Chapter 18—Project Management
Chapter 19—Contractors
Chapter 20—The Risk Management Professional

PROFESSIONAL ADVICE

> This book covers a wide range of professional topics such as health, human factors, and equipment design. It goes without saying that a properly qualified professional should be consulted for specific advice in specialized areas such as these.
>
> **Note**: This book also describes some of the regulations to do with safety, design and operations. However, because each country has its own legal system and regulatory interpretations are constantly changing, qualified legal advice should always be obtained for each particular system and location.

REGULATIONS, STANDARDS, AND GUIDANCE

The design and operation of process facilities is covered by a wide range of regulations, industry consensus standards, and guidance documents such as books, company standards, and manufacturer's information. Many of these documents are referred to and described in this book. The guidance provided here is general in nature; each company and facility should use the material provided as a basis for developing its own standards.

REGULATIONS

As the name implies, regulations must be followed—they are the law of the land. They can be national/federal, state/province, or local.

In the United States, many of the regulations to do with the safety of process facilities are written and enforced by the Occupational Health and Safety Administration (OSHA). It is often found that OSHA's rules and the interpretation of those rules are used internationally, even when there is no legal requirement to do so. The U.K. Health and Safety Executive (HSE) is another regulatory agency whose influence often extends beyond its own immediate jurisdiction.

Information as to how regulations are developed and enforced is provided in Chapter 2 of *PRRM*.

INDUSTRY STANDARDS

The International Organization for Standardization (ISO) defines a standard as a documented agreement containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes, and services are fit for their purposes.

In the process industries, consensus standards are published by bodies such as the American Petroleum Institute (API), the National Fire Protection Association (NFPA), and the American Society of Safety Engineers (ASSE). Generally, the standards are written by industry experts who pool their knowledge and experience while working together on a committee.

ISO also states that standards are developed according to the following principles:

- Consensus
- The views of all interests are taken into account: manufacturers, vendors and users, consumer groups, testing laboratories, governments, engineering professions, and research organizations.
- Industry-wide
- Global solutions to satisfy industries and customers worldwide

Although compliance with industry standards is usually voluntary, many of them—such as the API's Recommended Practice 14C—have been incorporated into law.

Two organizations, ISO and the American National Standards Institute (ANSI), help with the development and implementation of standards.

ISO

The International Organization for Standardization (ISO) has developed over 17,500 International Standards on a variety of subjects; some 1,100 new ISO standards are published every year. Two groups of standards—ISO 9000 (Quality Management Systems) and ISO 14000 (Environmental Management Systems)—are of particular relevance to the process industries.

The manner in which an organization implements and manages its ISO 9000/14000 programs is built around the following four steps:

1. It writes down what it is going to do.
2. It trains everybody to follow the standards that have been set.
3. It implements an audit program.
4. It suggests means for improving the present operation.

ANSI

The ANSI has an accredited Standards Developing Organization. This organization reviews procedures for writing standards in many of the standards bodies. For example, ANSI will review and accept the manner in which an organization resolves differences of opinion during the consensus phase of writing a new or revised standard.

GUIDANCE DOCUMENTS

Many companies write internal standards for their own use. Such guidance often reflects that company's knowledge of unique issues, such as the handling of a specialized chemical. These internal standards supplement the pertinent regulations and industry standards.

Guidance can also come from manufacturers and vendors. They know their own equipment or products very well indeed and can often provide excellent advice to do with operations and safety.

UNITS OF MEASUREMENT

The units of measurement used in this book are normally SI (*Le Système International d'Unités*, OI, 2006). However, many industrial standards have been developed by companies working with the traditional English/American units (sometimes referred to as *customary* units), and these are sometimes quoted here. Also, many of the standards that are currently in use are clearly based on the traditional units. For example, flash points are defined with the round number of 100°F (Fahrenheit). This converts to the more awkward 37.8°C.

RISK REDUCTION

The management or risk is central to much of what is written in this book. Decisions to do with topics as varied as vessel entry, the design of fire hydrants and the selection of process chemicals all require an understanding of the risks involved.

RISK ANALYSIS

The topics of risk analysis and risk management are discussed in depth in *PRRM*. Equation (1.1) shows the three key elements of risk:

$$\text{Risk}_{\text{Hazard}} = \text{Consequence} * \text{Predicted Frequency} \tag{1.1}$$

Equation (1.1) shows that risk can never be zero—a truth not always grasped by members of the general public or the news media. Hazards are always present within all industrial facilities. Those hazards always have undesirable consequences, and their likelihood of occurrence is always finite.

In general, the best way to reduce risk is to remove the hazard either by eliminating the item that is causing the risk or by removing persons from the scene of potential incidents. These approaches are summarized in the aphorisms, “If a tank’s not there, it can’t leak” and “If a man’s not there, he can’t be killed.”

If the hazard cannot be removed, the next best step is usually to reduce the consequence of the event. If that cannot be done, then the likelihood or predicted frequency should be reduced. The final and least satisfactory step is to add safeguards such as safety instrumentation or personal protective equipment (PPE) for the workers.

QUANTIFICATION

The importance of quantification is pointed out in two well-known quotations. The first, attributed to Peter Drucker, is “What gets measured gets done”. The second, attributed to W. Edwards Deming, is “In God we trust, all others must bring data.” Those managing process facilities should follow the advice of these two industry leaders. All decisions to do with operations, design, and safety should be analyzed quantitatively, wherever possible.

FLAMMABLE AND COMBUSTIBLE MATERIALS

This book contains many discussions to do with the control of flammable and combustible materials. The terminology used for this topic—which can be confusing—is explained in the following sections.

FLAMMABLE RANGE

Fires require the presence of fuel and air (oxygen) along with a source of ignition. These criteria are often referred to as the fire triangle.

The fuel has always to be in the form of a vapor (liquids and solids do not burn directly—the fire generates flammable vapors at their surface and it is the vapors that actually burn). Moreover, not all fuel vapor/oxygen mixtures will burn—the concentrations have to lie inside the flammable range, which have upper and lower limits for the concentrations of the fuel in the vapor space. The flammability limits vary according to many factors, of which some of the most important are the pressure and temperature of the mixture and the presence of inert components such as steam, carbon dioxide, or nitrogen.

FLAMMABLE LIMITS

The flammable range for a fuel is defined by the lower flammable limit (LFL) and the upper flammable limit (UFL). These terms are also referred to as the upper and lower explosive limits. Below the LFL, there is insufficient flammable material for a fire to occur—the mixture is "too lean." It is the lowest concentration of a flammable vapor in air capable of producing a fire in the presence of an ignition source.

The UFL is similar to the LFL except that there is too high a concentration of vapor for a fire to occur—the mixture is said to be "too rich."

For most flammable hydrocarbons, the LFL is around 2%−5%. For simple alkanes, such as methane and ethane, the UFL is in the 10%−15% range. Some chemicals, such as hydrogen, ethylene oxide, and acetylene, have much higher values for UFL. Values for flammable limit ranges for many flammable materials are provided by NFPA 704—Standard System for the Identification of the Hazards of Materials for Emergency Response.

FLASH POINT

The flash point of a flammable material is defined as the temperature at which a vapor that is inside its flammable range that can be ignited. An ignition source such as a flame or spark is needed to make the material actually burn. It is important to recognize that an ignition source is required. The flash point is not the same as the autoignition temperature (AIT).

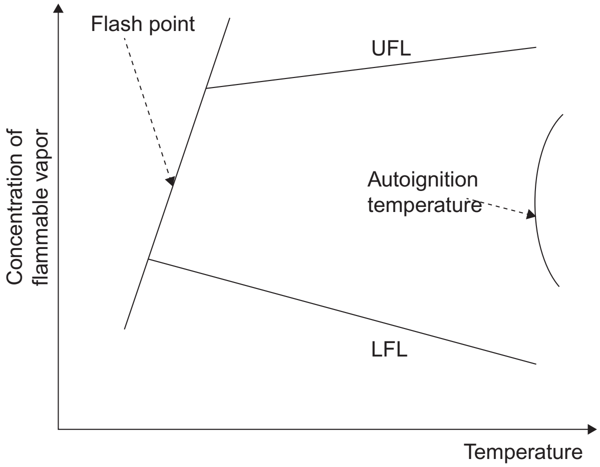

FIGURE 1.1

Flammability and ignition limits.

The flash point is determined by heating the liquid in test equipment and measuring the temperature at which a flash will be obtained when a small flame is introduced in the vapor zone above the surface of the liquid.

Figure 1.1 illustrates the concepts of ignition temperatures and flash points and flammable limits.

Before a flammable mixture will burn, its temperature must be at or above the flash point. If the temperature is below this point, then the vapor mixture will not burn, even if a source of ignition exists. The left line in Figure 1.1 is the flash point line.

Even if the material is above its flash point, the ignition source must be of sufficiently high temperature and must contain sufficient energy to ignite the fuel. The minimum energy varies with the type of gas and concentration; for hydrocarbon vapors it is low and for high flash point liquids, such as diesel and fuel oil, it is much higher—usually in the form of an existing fire. This is why low-energy flashes (such as that might be created by a mobile phone or a digital camera) may not ignite a flammable mixture.

If a flammable mixture is heated to a high enough temperature, it will spontaneously ignite; an ignition source such as a flame or spark is not needed. Spontaneous ignition occurs at the AIT, which is also shown in Figure 1.1.

COMBUSTIBLE LIQUIDS

A combustible liquid [see OSHA's 29 CFR 1910.106 (Flammable and Combustible Liquids)] is defined as having a flash point that is above 100°F (37.8°C). Combustible liquids are divided into one of the following two classes.

Class II liquids

This class includes liquids with a flash point at or above 100°F (37.8°C) and below 140°F (60°C), except any mixture having components with flash points of 200°F (93.3°C) or higher, the volume of which make up 99% or more of the total volume of the mixture.

Class III liquids

This class includes combustible liquids with a flash point at or above 140°F (60°C). Class III liquids are subdivided into the following two subclasses:

- Class IIIA liquids have a flash point at or above 140°F (60°C) and below 200°F (93.3°C), except any mixture having components with flash points of 200°F (93.3°C), or higher, the total volume of which make up 99% or more of the total volume of the mixture.
- Class IIIB liquids have a flash point at or above 200°F (93.3°C).

In general, the term "Class III liquid" means "Class IIIA" unless specified otherwise.

When a combustible liquid is heated to within 30°F (16.7°C) of its flash point, it shall be handled in accordance with the requirements for the next lower class of liquids.

- Flammable liquid: any liquid having a flash point below 100°F (37.8°C), except any mixture having components with flash points of 100°F (37.8°C) or higher, the total of which make up 99% or more of the total volume of the mixture. Flammable liquids shall be known as Class I liquids. Class I liquids are divided into three classes as follows:
  - Class IA includes liquids having flash points below 73°F (22.8°C) and having a boiling point below 100°F (37.8°C).
  - Class IB includes liquids having flash points below 73°F (22.8°C) and having a boiling point at or above 100°F (37.8°C).
  - Class IC includes liquids having flash points at or above 73°F (22.8°C) and below 100°F (37.8°C).
- Liquids having flash points below ambient storage temperatures generally display a rapid rate of flame spread over the surface of the liquid, since it is not necessary for the heat of the fire to expend its energy in heating the liquid to generate more vapor.

FLAMMABLE LIQUIDS

Since it is the vapor of the liquid, not the liquid itself that burns, vapor generation becomes the primary factor in determining the fire hazard. Hence liquids that have a flash point below ambient temperature generally have a rapid rate of flame spread over the surface of the liquid because it is not necessary for the heat of the fire to expend its energy in heating the liquid to generate more vapor.

If ambient temperature is defined as being 100°F (37.8°C), then any liquid having a flash point below that value is said to be flammable, as distinct from just combustible. Flammable liquids are known as Class I liquids. There are three subclasses, which are as follows:

1. Class IA includes liquids that have a flash point below 22.8°C (73°F) and a boiling point below 37.8°C (100°F).
2. Class IB includes liquids that have a flash point below 22.8°C (73°F) and a boiling point at or above 37.8°C (100°F).
3. Class IC includes liquids that have a flash point at or above 22.8°C (73°F) and below 37.8°C (100°F).

Given that the above definitions are quite complex and can be confusing, OSHA developed the sketch shown in Figure 1.2 to help clarify the terms used.

IGNITION SOURCES

It has already been stressed that most fires require an ignition source and that the ignition source should have sufficient energy and temperature to actually cause the vapor fuel to burn. Therefore, it is very important to identify all ignition sources at a facility and, where possible, to eliminate them.

Some of the more common sources of ignition in process facilities include the following:

- Flames and hot surfaces
- Wiring (overhead and buried)
- Electrical equipment
- Low voltage devices
- Stray currents

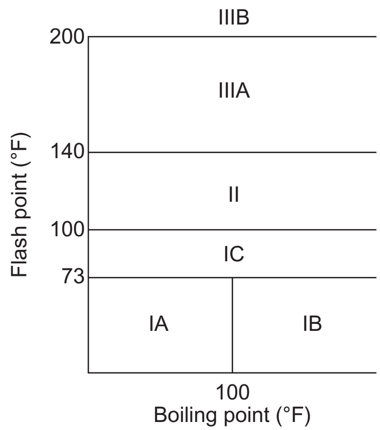

FIGURE 1.2

Flammable and combustible liquids.

- Electrostatic charges
- Lightning
- Hot work
- Sparks from tools
- Radiant heat
- Iron sulfide (FeS)

In some processes air is routinely allowed to contact hydrocarbons. Examples include some treating processes in refineries and some atmospheric fixed roof tanks. In such situations, the potential for a fire can be controlled by eliminating any ignition sources, maintaining a hydrocarbon/oxygen mix that is outside the flammable range, and installing equipment such as flame arrestors to prevent flame propagation.

AREA CLASSIFICATION

Many of the decisions to do with safe operations and maintenance depend on the area classification systems that is being used. Area classification is primarily to do with the design of electrical systems. However, the guidance provided can be used whenever flammable materials are present, regardless of the potential sources of ignition. Therefore, an overview of the topic is provided here.

The three systems most commonly used are as follows:

- The National Electrical Code (NEC) from the National Fire Protection Association (NFPA 70)
- The Canadian Electrical Code
- The (International Electromechanical Commission) IEC European code

The three systems are broadly similar and there are ongoing efforts to harmonize them. In all cases, the hazardous area is defined by the following three major criteria:

1. The type of hazard
2. The likelihood of the hazard being present
3. The ignition temperature of the hazardous material

The NEC system consists of the following three classes:

1. Combustible gases and vapors
2. Dusts
3. Fibers and flyings

Most applications in the process industries fall in Class I, which itself is divided into the following two divisions. Division 1 covers areas where:

- Ignitable concentrations of flammable gases or vapors are present under normal operating conditions.
- Ignitable concentrations of flammable gases or vapors may exist frequently because of repair, maintenance operations, or leakage.

- Where breakdown or faulty operation of equipment or processes may cause a release of ignitable vapor and a simultaneous failure of electrical equipment that could become a source of ignition.

Division 2 covers areas where:

- Volatile and flammable liquids and gases are handled, but where the process fluids are normally confined in closed systems and will only escape in the event of an accident or abnormal equipment operation.
- Concentrations of flammable gases could become ignitable in the event of a failure of venting equipment.
- The storage tanks of volatile and flammable liquids and gases are adjacent to Class I/Division 1 areas but are not separated by a tight barrier.

In order to declassify the interior of a building (such as control rooms, living quarters, or labs) that is inside a classified area, the occupied space must be purged and pressurized. A general rule is that there should be at least 12 air changes per hour.

HOUSEKEEPING

Good housekeeping is central to all types of operational, maintenance, and safety work. The quality of housekeeping also provides auditors and other outsiders with an opportunity to provide a quick evaluation of the overall level of operational excellence in a facility. In the words of the proverb, "You don't get a second chance to make a first impression." And it is housekeeping that creates that first impression. Housekeeping also provides a quick check regarding culture and employee participation since everyone has an impact on the appearance of the facility.

GENERAL NEATNESS

The first, and the most obvious, aspect of housekeeping is general neatness. The following checklist provides some of the instructions that should be followed to ensure a high level of housekeeping:

- Ensure that all discarded materials, particularly those that are potential fire hazards, are disposed of properly and continuously throughout the job progress.
- Avoid accumulation of combustible items such as spilled oil, woods, and rags because they can be a fuel source during a fire. Oil-soaked rags should always be promptly disposed of in covered metal cans.
- Remove tripping hazards.
- Keep drain openings and free-flowing drainage systems free of debris.

- Keep aisles and walkways free and clear of maintenance equipment and tools in order to eliminate tripping hazards and to ensure that emergency evacuation is not restricted and that access to firefighting equipment is not hampered.
- Ensure that junction and switch box covers on electrical circuits are secure and tight.
- Promptly eliminate trace hydrocarbon leaks from lines, valves, and stuffing boxes (this is often a strict requirement of the environmental regulations).
- Remove and replace oil-soaked insulation.
- Clean up spills at once.
- Nails, staples, and other puncturing metals should be bent under or removed from spent packing or lumber and stacked with points on bottom.

PROPER PLACEMENT

Proper placement means "a place for everything and everything in its place." Tools should be in their correct location and all firefighting equipment is where it should be and ready to operate immediately.

Stacked material should be secured to prevent materials from falling over, with the heaviest objects closest to the floor.

GRASS AND BRUSH

Dry grass, brush, or weeds can help spread a fire or transfer a fire from one area to another. On most properties, this can be avoided by appropriate use of weed killers and/or mowers. In some locations, carefully controlled and supervised burning of dry grass and weeds will reduce the risk of accidental fire.

EQUIPMENT AND PIPING

Housekeeping includes checking that equipment and piping is in good condition. All process and utility piping should be horizontal or vertical (a few process applications do call for piping to be sloped). Any equipment that is in a deteriorated condition, say due to corrosion, should be identified and a repair work order issued. Damaged or contaminated insulation should be replaced, along with the insulation covers.

STORAGE AND HANDLING OF FLAMMABLE LIQUIDS

The storage and handling of flammable and combustible liquids can be hazardous since workers are often working closely with the containers and their contents. Also, the vapors generated by the liquids can be close to sources of ignition such as an internal combustion engine.

Regulations and standards

Guidance to do with the handling and storage for flammable and combustible liquids is provided by OSHA's 29 CFR 1910.106 and by NFPA 30, the Flammable and Combustible Liquids code. The OSHA standard applies to flammable and combustible liquids with a flash point below 200°F (93.3°C). These reference documents provide definitions for terms such as closed container, fire area, and aerosol.

Guidance to do with the design and construction of containers is provided in 49 CFR 173 and 178. They provide information to do with the management of containers for flammable and combustible liquids. Topics covered include the following:

- Containers
- Storage cabinets
- Storage rooms
- Wiring
- Ventilation
- Buildings
- Offices
- Warehouses
- Fire control
- Point of final use

Handling requirements

The following guidance should be considered when handling flammable and combustible liquids:

- Flammable liquids shall be kept in closed containers when not actually in use.
- Flammable liquids may be used only where there are no open flames or other sources of ignition within the possible path of vapor travel.
- Flammable or combustible liquids must be drawn from or transferred into vessels, containers, or portable tanks within a building only through a closed piping system, from safety cans, by means of a top drawing device/pump, or from a container or portable tank by gravity through a self-closing valve.
- Transferring flammable or combustible liquids by means of gas or air pressure on the container or portable tanks is not allowed.
- Flammable liquids shall not be dispensed into containers unless the nozzle and container are electrically interconnected. This can be satisfied by:
  - Having a metallic floor-plate on which the container stands while the fill pipe or nozzle is electrically connected to the container or plate.
  - Bonding the container to the fill stem by means of a bond wire.
- Plastic containers should not be used to collect, store, or transfer flammable liquids unless the fluids could react with a metal container.
- Similarly, combustible or flammable liquids should be stored in metal tanks or containers unless the product being stored will cause a reaction with the vessels.

NONPROCESS OPERATIONS

Not all incidents and mishaps at process plants take place in the actual processing areas. Some guidance as to how to manage nonprocess operations is provided in the following sections.

OUTSIDE STORAGE

Although most process operations happen inside equipment and pipes, outside areas are often used for storage. In such situations, the following guidelines should be considered:

- All outside storage areas should be kept free of grass, weeds, and other combustibles. Cuttings should be removed.
- Smoking should be permitted in authorized smoking areas only.
- Travel distance from any point to an extinguisher should not exceed 25 meters.
- Hydrants should be provided so that all storage areas can be reached by at least two hose streams. A minimum spacing of 75 meters between hydrants should be provided.
- Storage piles should be as low and as stable as possible, with a 3-meter minimum width. Aisles should be provided between storage piles, piles and buildings, and piles and boundary lines.

Combustible materials such as wood or paper-based packing materials should not be stored in hydrocarbon processing areas. It is particularly important to ensure that the area around the base of flare stacks is kept free of combustibles because the radiant heat from the flare can be sufficient to cause ignition.

COAL AND COKE STORAGE

Bituminous coal and green coke (but not calcined coke) are subject to spontaneous heating and any fires are very difficult to extinguish. The following safeguards should be implemented:

- Air movement through the pile should be prevented as far as possible. This can be aided by compacting the coal.
- The internal temperature of the pile should be monitored regularly—say once a week. If temperatures reach 70°C, the hot area should be exposed by dispersing the pile.
- The pile should not be exposed to heat sources and it should be kept away from other combustibles.
- Coal bins should be of noncombustible construction.

DRUM STORAGE

The following guidance should be considered with regard to drum storage in open areas:

- Drum storage areas should be graded and have drains in order to divert spills from buildings or other critical areas.
- The drainage should be at a safe location.
- Drum storage areas should be at least 15 meters from other structures.
- Aisle and fire protection should be provided.
- Empty drums that were used for the storage of flammable or combustible liquids present a fire hazard due to vapors which still may be present in the drums. Therefore, all drums (full and empty) should be sealed wherever possible.

DRAINAGE

It is important that drains from the process areas do not enter unclassified nonprocess locations. Otherwise flammable or toxic vapors may be released in nonclassified areas. In particular, process drains should not be located close to occupied buildings.

Drainage from the nonprocess areas should not enter the process drains so that the oil—water sumps and treatment facilities are not overloaded with water that does not require treatment.

Further discussion to do with the layout of drains is provided in Chapter 11.

FIRE PROTECTION AND PREVENTION

All cutting and welding should be done in areas that have been made fire safe by removal or protection of all combustibles. Typically, no combustibles without flame-resistant covers should be located within a 10-meter radius of the work area. All openings or cracks in walls and floors should be covered. Charged fire extinguishers and noncombustible fire blankets should be available at the work site. A fire watcher should be designated in areas where the potential for a serious fire exists.

CYLINDERS

The following guidance is provided regarding the storage and handling of cylinders containing hazardous materials:

- Cylinder storage areas should be prominently posted with the names of the gases that are permitted to be stored there.
- Where gases of different types are stored at the same location, cylinders should be grouped by type of gas and the groups arranged to take into account the gases contained. For example, oxidizing gases should be stored separately from hydrocarbons.

- Cylinders should be stored so as to minimize handling when they have to be moved. Full and empty cylinders should be stored separately.
- Cylinder storage rooms should be well ventilated and dry and should be of fire-resistive construction. Storage room temperature should not exceed 55°C (depending on the cylinder contents).
- Cylinders should be stored in a secured vertical position.
- They should not be located within 6 meters of readily ignitable substances such as gasoline or combustible waste, or near combustibles in bulk, including oil.
- Cylinders should not be exposed to continuous dampness, salt, or other corrosive chemicals or fumes.
- Cylinders should not be stored near elevators, gangways, unprotected platform edges, or in locations where heavy moving objects may strike or fall on them.

LOADING RACKS

At many process facilities, the loading and unloading of trucks presents a major hazard. A spill can lead to a fire and/or a major environmental violation. The following principles should be noted with respect to loading racks and vehicle movement associated with loading and unloading. (The layout of loading and unloading racks is discussed in Chapter 11.)

- Generally, a tank loading area is Class I, Division 2, unless otherwise specified.
- There should be clear, unrestricted truck access during peak hours.
- Access routes should not require tank truck paths to cross on entry and exit.
- Access should not conflict with or congest access to adjacent facilities.
- There should be a waiting area for trucks standing by that allows orderly evacuation in case of emergency, without cross traffic or confusion.
- There should be a parking location for trucks making load and seal checks and completing final paper work.
- Weather protection canopies should not impede emergency access or restrict application of firewater or foam.
- Each bay should be isolated by high points and grading that slopes to the sealed catch basin. This prevents liquids from accumulating under vehicles in adjacent bays.
- Drainage should be away from the loading rack, occupied buildings, and waiting trucks.
- Drain inlets should be located between truck and rack piping, away from areas where a driver might be standing, such as the loading point or an emergency shutdown (ESD) switch.
- If possible, there should be a low point drain between the loading rack and the line for waiting trucks.

- The loading rack area should be paved.
- Truck-filling valves should be of the spring-loaded, self-closing type.
- ESD stations should be located at each end of the rack for bottom-loading facilities and at the base of each stairway for top-loading racks.
- Overhead lights must be installed so they will not be struck and broken by movement of the loading arms.
- The cover of the filled compartment should be closed before opening the next compartment.

If tank cars are filled or drained too quickly, static electricity may build up and create a spark. In general, the following guidelines should be followed:

- The truck should be bonded to the loading piping before opening any compartment.
- The loading arm should be extended down to the bottom of the tank so as to avoid splashing.
- Liquid velocities should be kept below 1 m/s until the bottom of the fill spout is covered with liquid and there is no splashing. The velocity can be increased after the fill spout is covered.
- After loading or emptying is complete, there should be a pause of at least 1 minute before gauging or sampling is carried out.

SIMULTANEOUS OPERATIONS

Whenever two or more project or maintenance activities are being conducted at a facility at the same time, a Simultaneous Operations (SIMOPs) Plan is needed in order to ensure that potential clashes do not create environmental or safety problems. An effective SIMOPs program is particularly needed at offshore facilities because they are so congested and because multiple activities such as drilling, diving, boat unloading, and production could all be going on at one time.

SIMOPs often involve multiple companies, large multidiscipline workforces, and a wide range of routine and nonroutine activities. They often occur whenever construction or major maintenance work is being done within an operating process area of an existing facility. One example could be the lifting of heavy equipment over the piping of a production facility that has not been shut down.

In addition to technical and operational concerns, SIMOPs may also involve contractual, liability, and insurance issues.

SIMOPs involve many of the elements of a Safety Management System—particularly Management of Change, Mechanical Integrity, and Hazards Analysis. (These topics are discussed in detail in *PRRM*.) For example, a hazards analysis group may be evaluating a proposed equipment change. Their analysis may recommend that all sources of ignition be shut down while the change is being made. But, in a SIMOPs environment, those managing other activities may not be aware of the team's recommendation and may allow activities such as welding to take place.

Key elements of a SIMOPs management program include the following:

- Communication
- Risk assessment
- Control
- Coordinate
- Single point contact person who has overall authority

Guidance to do with the development and implementation of an offshore SIMOPs plan is provided by the International Marine Contractors Association (IMCA 2010).

MANAGING SIMOPs

The first step in managing SIMOPs activities is to realize that they are happening. The various groups who are conducting normal operations, maintenance, and construction work at a location need to be aware of one another's existence and what they are doing. Hence there needs to be one person who is aware of all activities that are taking place at the facility, and who has the authority to change or stop those activities. This person is often referred to as the Person in Charge (PIC).

For all but the smallest SIMOPs activities, the PIC will appoint a SIMOPs coordinator. It is this person who will develop the plan, communicate its requirements to the parties involved, and who will inform the PIC as to the status of the various projects.

The SIMOPs coordinator needs to learn from each of the groups doing the following work:

- The different types of hazards analysis that have been carried out, and the recommendations and actions from each. The analyses can cover issues such as dropped objects from cranes or release of gas from a high pressure system.
- The Management of Change package that was used for each task or activity.
- Escape route identification.
- Weather limitations.
- Communications between the work leaders, the other work groups, and the SIMOPs coordinator. This step includes knowing what to do if communications fail for any reason.

SIMOPs MATRIX

A SIMOPs matrix that provides guidance and instructions as to what activities can be carried out at the same time can be developed. Figure 1.3 is an example of such a matrix. It shows the activities for two companies: X and Y.

	Y1	Y2	Y3	Y4	. . .
X1	A	P	P	P	
X2	A	A	R	R	
X3	A	A	R	P	
X4	R	A	P	P	
. . .					

FIGURE 1.3

SIMOPs matrix.

A (allowed)	The two operations can be carried out simultaneously as long as a SIMOPs process is in place and all normal control activities are followed.
P (prohibited)	Concurrent operations of the two activities are never allowed.
R (restricted)	Concurrent operations are allowed with additional controls in place, and with written permission from the OIM (Offshore Installation Manager).

FIGURE 1.4

SIMOPs matrix legend.

The legend for Figure 1.3 is shown in Figure 1.4.

In this example, the two companies can conduct activities X1 and Y1 at the same time; they can conduct X4 and Y1 at the same time, but with special precautions; but they can never conduct X1 and Y2 at the same time. Figure 1.1 also shows that activity Y4 needs close attention since all of the matrix values are either "R" or "P."

CONDUCTING THE SIMOPs

Communications are always important, but with SIMOPs they are critically important. It is vital that the parties who are doing work know what the other parties are doing and that the PIC and the coordinator always understand the big picture.

The SIMOPs program should start with a kickoff meeting that will be followed with regular and frequent communication meetings.

Kickoff meeting

Once the various SIMOPs activities have been identified, a kickoff meeting should be arranged so that the various Scopes of Work can be explained to the affected parties.

The meeting should:

- Identify all the SIMOPs activities that are to be included.
- Identify those activities that need a formal risk assessment to be carried out.
- Prepare mitigation and emergency response plans.

Once the kickoff meeting has been concluded each of the parties involved should identify how their work may impact others. They will need to identify issues such as the following.

- A summary of the work to be done in a step-by-step manner.
- Scale drawings associated with each step. Exclusion and restriction zones should be marked on the drawings.
- Constraints affecting each activity.
- An organization chart.
- A hazards assessment for the work to be done. The risk associated with each hazard should be summarized in a risk register.
- Mitigation and emergency response strategies, including escape routes.
- Weather and other external issues.
- Communications procedures with all other organizations involved in the SIMOPs work.

At the conclusion of the kickoff phase, an Interface Document should be prepared by the SIMOPs coordinator. It should summarize the work that has to be done, the roles and responsibilities of each party, and a matrix showing which activities may be carried out at the same time.

This document should cover the following:

- Roles and responsibilities
- Reporting relationships
- Procedures and controls
- Contingency and emergency plans
- Change control
- A clear definition of who has overall charge of the work (the PIC)
- Communications, including what to do if communications break down

Communication meetings

Once the SIMOPs have started regular communications involving all parties must be carried out. The meetings, which should be held at least daily, will cover work completed, work to be done, management of change issues, and changes to the emergency procedures. Topics to be discussed include the following:

- Names and roles of key personnel and their lines of communication.
- Review the location and function of all emergency alarms and alarm stations.
- Review the emergency response and evacuation plans, including an overview of muster locations.
- Review the facility’s accident and spill reporting procedures.
- Review first aid and medical evacuation procedures.
- Identify any restricted access areas, and means of control of those areas.
- The smoking policy.

The PICs of a task or activity must inform the SIMOPs coordinator when their work is done, and that the system has been returned to its normal state (or that an Operational Readiness review is now needed for systems that have been modified). Problems with false assumptions to do with closeout were a major factor in the Piper Alpha accident.

CLOSEOUT

Once the SIMOPs work is concluded, the parties involved should conduct a closeout meeting to identify lessons learned for future projects of the same type. The closeout should include completion of the Management of Change process.

EXAMPLES

In *PRRM*, a set of worked examples was provided to illustrate many of the concepts and ideas that were presented in that book. Two of those examples are repeated here and used in later sections of this book. The examples are also available at http://www.stb07.com/downloads/process-industry-examples.pdf.

EXAMPLE 1—FACILITY DESIGN

A process consists of four operating units and a utilities section. A schematic of the system is shown in Figure 1.5.

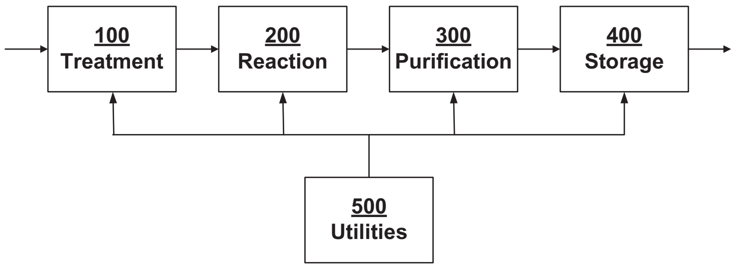

FIGURE 1.5

Process units.

EXAMPLE 2—HEAT EXCHANGER

Figure 1.6 shows a shell and tube heat exchanger. Hydrocarbon vapors enter the exchanger on the shell side where they are condensed by cooling water which runs through two passes of tubes. The pressure relief valve and the drain and vent valves on the shell side are shown.

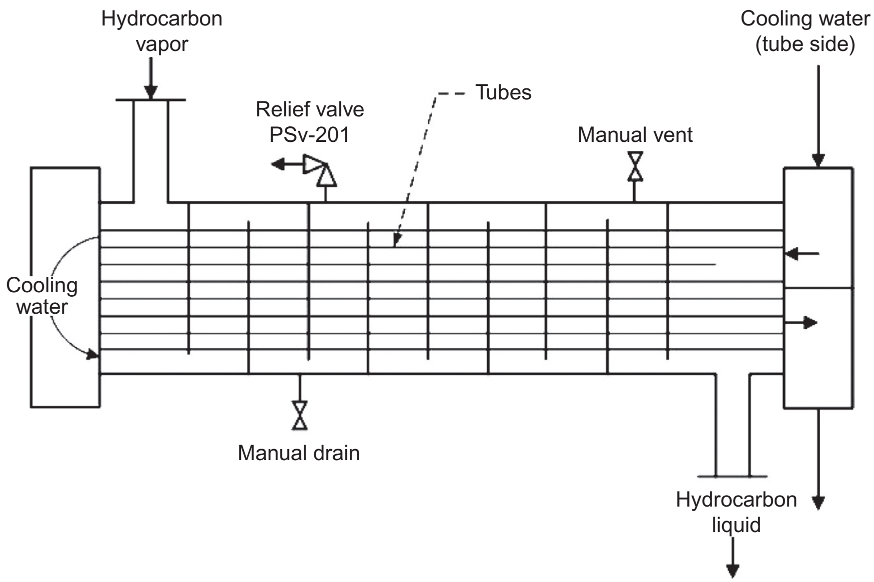

FIGURE 1.6

Heat exchanger example.

CHAPTER

2 Maintenance and inspection

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00002-0

INTRODUCTION

The previous chapter discussed some of the operating issues to do with process facilities. This chapter describes the related topic of maintenance, where the term maintenance refers to repairing equipment that has failed or taking corrective action before the item actually does fail. Larger changes to the system are handled through the Management of Change (MOC) program—discussed in detail in *Process Risk and Reliability Management.* Even larger changes constitute stand-alone projects in their own right.

Also discussed in this chapter are inspection and the terms "Mechanical Completion" and "pressure test."

TYPES OF MAINTENANCE

Maintenance work falls into one of the following four categories:

1. Repair
2. Condition-based maintenance
3. Scheduled maintenance
4. Reliability-centered maintenance (RCM)

All but the first of these can be placed in the overall category of preventive or preventative (either spelling is acceptable) maintenance.

REPAIR MAINTENANCE

The most common type of maintenance is the repair of an item which has failed or which is showing imminent signs of failure. This type of maintenance tends also to be the most hazardous because there may not be much time to plan the job, and the repair work may be going on while the rest of the facility is in operation. In addition, the maintenance workers may be under pressure to get the work done quickly in order to avoid a larger system shutdown. Such pressure may lead to shortcuts being taken.

CONDITION-BASED MAINTENANCE

Condition-based maintenance is carried out when an equipment item starts to show early signs of failure or when its performance becomes degraded.

For example, if the discharge pressure of a pump starts to fall the pump may be taken out of service and repaired before it actually fails.

Condition-based maintenance tends to be less hazardous than repair maintenance because it can be properly planned, and it can be carried out without the workers feeling that they are in a rush. Ideally, condition-based maintenance will be carried out while the unit is shut down, thus making conditions even safer for the maintenance workers.

Examples of monitoring activities that could lead to the need for condition-based maintenance include the following:

- Process performance
- Vibration analysis
- Oil analysis
- Thermography.

SCHEDULED MAINTENANCE

Some equipment and instrument items are serviced on a scheduled basis, regardless of the actual performance or condition of those items. A common example of this type of maintenance is the routine replacement of lubricating and seal oils.

Table 2.1 provides an example of the maintenance schedule of an instrumentation system.

RELIABILITY-CENTERED MAINTENANCE

Reliability-centered maintenance (RCM) uses a risk-based approach to organizing maintenance activities. As such, it is analogous to risk-based inspection (RBI), a topic that is discussed later in this chapter. This approach is based on the elements of risk as shown in Equation (1.1). Those items that contribute the most to overall risk receive a higher maintenance priority than those that are considered to be less critical. (In practice, the RCM program may focus more on the consequence term than on overall risk.)

Table 2.1 Example of an Instrument Loop Maintenance Schedule

Item	Months
High integrity protection loops	6
Shutdown and alarms systems (SIL2)	6
Shutdown and alarms systems (SIL1)	12
Control and monitoring systems	24
Nonsafety alarms	24
Indicators	24
Ancillary instruments	36

An RCM analysis is typically built around the following steps:

1. A component list is developed for the section of the facility that is being analyzed.
2. A failure analysis, possibly using the Failure Modes & Effects Analysis (FMEA) method, is carried out for each component.
3. A criticality is assigned to each failure mode.
4. A scheduled maintenance program that focuses on the high criticality items is set up. This program can be condition-based.

The RCM program should include a process for analyzing equipment failures and applying the lessons learned from those analyses such that overall risk can be reduced. The analysis can also help determine the required inventory for spare parts.

MAINTENANCE TASK ORGANIZATION

The organization of a maintenance task can be divided into the following eight steps:

1. Plan the work
2. Conduct a risk assessment or job hazards analysis (JHA)
3. Issue a work permit and prepare tools and personnel
4. Shutdown and isolate the affected equipment
5. Make the first break
6. Perform the work
7. Close out the work and the permit
8. Handover to operations

Figure 2.1 shows an overview of the above steps.

STEP 1—PLAN THE WORK

The first step is to determine what the task is and how it is to be done. This step also means identifying and listing the affected pieces of equipment and determining what impact the maintenance work is likely to have on the overall operation. For a large, continuously operating unit, an important part of the plan is to determine what other parts of the facility will have to be shut down and to determine how those items that are to be left running are to operate during this particular maintenance task. Therefore, an isolation plan is required.

It is very important at this stage to determine if the work is truly routine maintenance, or if it falls under the scope of the MOC program.

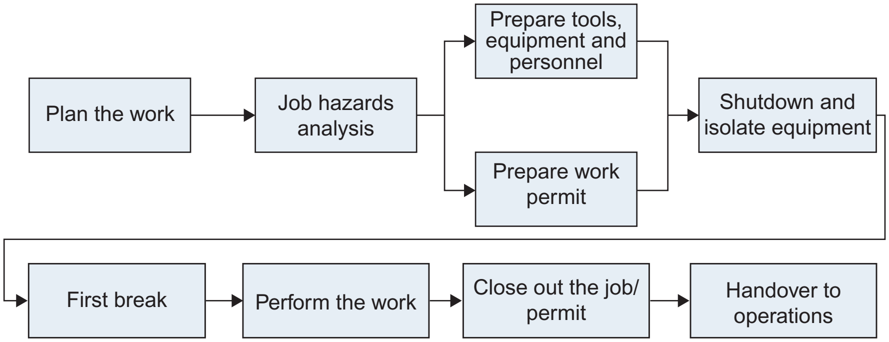

FIGURE 2.1

Maintenance planning.

Before maintenance work starts it is important to check that the following activities have been carried out:

- All equipment is either on site or scheduled for delivery (components should be assembled in an area adjacent to where the work is taking place).
- Piping is fabricated in advance.
- Everything is field verified and measurements are checked.
- As-built drawings are updated or verified.
- The path of travel for each piece of installed equipment is identified, as well as for any heavy construction equipment needed.
- Construction materials are placed in convenient locations and safety gear and special equipment are prepositioned in prepackaged kits near the work area.
- Spare parts and consumable supplies are fully stocked.
- The turnover/start-up plan has been reviewed by all affected parties.

The job plan should include the following items:

- Equipment description
- Location of the work
- Work description
- Time needed for the work
- Name of person(s) requesting the work
- MOC clearance—if needed
- Sources of high energy normally present
- Isolation points
- Lock/tag applications at each isolation point

- Shutdown procedures
- Methods for removing stored/residual energy
- Tools and equipment needed for the work
- First break procedures
- Identification of all personal tags and locks
- Sign-off procedures for job completion
- Sign-off procedures for putting equipment back in service

STEP 2—CONDUCT A JHA

For all but the simplest jobs a JHA or job safety analysis (JSA) should be carried out before a permit to work is issued. The analysis consists of the following steps:

- Analyze each task in order to identify the associated hazards.
- Assess the consequence, likelihood, and risk of each of the identified hazards using a risk matrix system such as that described in Chapter 1.
- Ensure that sufficient precautions (safeguards) have been put in place to place the risk in an acceptable range.

Depending on the nature of the task to be analyzed, a JHA can be conducted at the following one of three levels:

1. For simple, low-risk jobs that have been carried out before, a pre-job discussion and tailgate/toolbox talk will generally be sufficient.
2. For more complex tasks, permit discussions and a review of the precautions required in the permit should be carried out.
3. For more complex and risky tasks (which always include any kind of equipment entry or line break), a full hazards analysis should be performed.

Figure 2.2 shows an outline of JHA form (an actual form would contain more boxes for information about the job, such as where it is and who is working on it). There would also be space for signatures.

STEP 3—ISSUE A WORK PERMIT

Once the job scope has been defined and a hazards analysis performed, a work permit is issued by the operations department. The permit will include all information needed to ensure that the maintenance work is carried out safely. In order to save time, the tools, equipment, replacement parts, and personal protective equipment (PPE) that will be needed can be assembled in parallel with the permitting steps, as shown in Figure 2.1.

JHA #		Date:	
Location			
Task description			
Reference documentation			
Risk assessment leader			
	Consequences	Likelihood	Risk
Hazard 1			
Safeguards			
Hazard 2			
Safeguards			
Hazard 3			
Safeguards			
Hazard 4			
Safeguards			
Hazard 5			
Safeguards			

FIGURE 2.2

Simplified JHA form.

STEP 4—SHUTDOWN AND ISOLATE EQUIPMENT

The next step is to determine how the affected unit(s) are to be shut down. The shutdown procedure may be included in the standard operating procedures. However, in many cases, maintenance work involves carrying out unusual or non-standard tasks. In such cases, temporary operating procedures will be needed, particularly if it is intended to keep the facility operating while the maintenance work is being carried out. Issues to watch for include the following:

- Sudden changes in utilities consumption
- Inventories of intermediate chemicals
- Changes in flow rates

Once the equipment is shut down, it can be isolated, vented, and drained.

STEP 5—FIRST BREAK

The workers can then carry out the “first break,” i.e., they open the first flange or electrical connection. It is when the workers are actually exposed to the system for the first time. This is a potentially dangerous time because, if the preparations have not been carried out properly, there may be an unexpected release of hazardous materials. Therefore, it is normal for extra precautions, such as the use of more PPE, to be undertaken at this time.

When separating the flanges of a line, consideration should be given to installing a grounding lead, which should be installed across the sections of pipe to be parted to protect against stray currents generating a spark when parting the line. Stray currents could be generated by energy sources that have not been properly deenergized, such as cathodic protection of the pipe system or nearby equipment. The discussion to do with installing blinds provided later in this chapter also provides guidance to do with breaking flanges.

STEP 6—PERFORM THE WORK

Once the first break has occurred, and assuming that everything is in order, the workers can carry out the maintenance task.

STEP 7—CLOSE OUT THE WORK/PERMIT

It is important to be vigilant during the restart process because there is often a temptation to skip steps in order to get the unit back into full operation as quickly as possible.

When the work is complete all copies of the permit should be returned to the issuing point. The permit-issuer should then inspect the worksite to confirm that the work has been completed as intended and that the worksite has been left in a safe and tidy condition, that all blinds have been removed, and that there are no other open permits that apply to the same equipment. Only then should the permit-issuer sign off the permit.

Closing out the permit does not necessarily mean that the equipment is ready to start up. In particular, a tightness pressure test must be performed. A housekeeping check should also be carried out, with particular focus on the following:

- All trash has been removed
- All unused materials have been removed
- All scaffolding has been dismantled
- The site has been washed down
- Unused parts have been returned to the store
- The site is in a clean, tidy, and safe condition

STEP 8—HANDOVER TO OPERATIONS

Once the maintenance work is complete, the equipment and instrumentation are handed over to operations.

Readiness review

An Operational Readiness/Prestartup Safety Review may be needed, particularly if the design of the system was changed in any way or if process conditions will change following the maintenance work. For large maintenance tasks, a turnover package may be required. (Information on these topics is provided in *Process Risk and Reliability Management.*)

It is important that the maintenance team report on what they observed and the actions that they took, along with suggestions as to how the equipment or system can be improved. This information provides management with insights as to how equipment and systems can be improved so as to reduce the number of future breakdowns and reduce maintenance costs.

Mechanical completion

Before a facility or piece of equipment is handed over to operations from maintenance, it should meet the following criteria before being considered as being mechanically complete. (If the item is brand new, then it will need to undergo a Factory Acceptance Test—a topic that is discussed in Chapter 12.)

Physically complete and clean

All piping, vessels, heat exchangers, and other equipment should have been flushed, cleaned, and dried. Equipment should be inspected to ensure that new welds are complete, all valves are closed with plugs installed, blinds of adequate thickness are installed, and all supports are in place.

Any new equipment should have been manufactured, fabricated, installed, and connected in accordance with the scope of work, the specifications and the design drawings. Temporary equipment needed for commissioning and start-up should be installed.

Tight

The system should be pressure tested (details are provided in the next section). There should be no loss of pressure or leakage from equipment, piping, and joints during hydrostatic/pneumatic testing.

Inspected, tested, and documented

Inspections (both shop and field) should cover the following items:

- Bench calibration of instruments
- Electrical insulation tests
- Nondestructive testing (NDT) and pressure testing of piping

- Integrity testing of valves
- Structural fabrication and welding
- Equipment alignment
- Painting

PRESSURE TESTS

After a piece of equipment or piping that operates under pressure has been opened and then reassembled ("buttoned up") it must be pressure tested before being put back into service.

There are two types of pressure test. The first is a tightness test, used after the equipment has been opened but not modified in any way. Typically this type of test is conducted after the item was opened for cleaning, inspection, or routine maintenance. The test ensures that the equipment is leak-free but it does not test the integrity of the vessel or piping itself. Tightness tests are never conducted at a pressure above the equipment or system design pressure or the relief valve set pressure.

The test pressure is generally 1.5 times the design pressure or MAWP (see below for an explanation of this term). Therefore, once a vessel has been installed, or anytime it is opened (say for inspection), it will be tested to that pressure before the process fluids are introduced into the vessel.

The second type of pressure test is a strength or hydro test. It is used when the equipment has been modified, say by having some welding done on it, or when structural repairs have been made. Strength test pressures are generally above the equipment or system normal design pressures or relief valve set pressure.

Regardless of the type of test being carried out, it is important first to visually inspect the equipment and to carry out the actions discussed above to do with mechanical completion.

MAXIMUM ALLOWABLE WORKING PRESSURE

Pressure vessels must always operate at a pressure lower than their maximum allowable working pressure (MAWP). The manner in which MAWP is determined can be illustrated using pressure vessel V-101 in the second standard example (Chapter 1).

1. In the initial design, the process engineer specifies that V-101 be designed for a maximum operating pressure of 6.5 barg. This is the design pressure or pressure rating of the vessel as measured at the top of the vessel.
2. The process engineer's requirements are transmitted to the vessel engineer who designs the vessel using standard sizes for wall thickness and flange size, thus generating the MAWP value. Generally, MAWP will be higher than the design pressure because wall thicknesses are in discrete sizes and the designer

will always choose a value greater than that called for. In the example, since it is unlikely that he can design for exactly 6.5 barg, the designer selects the next highest level, which, in this example, is 7.0 barg. Therefore, the vessel's MAWP is 7.0 barg.

3. Once in service, the vessel can be operated at any pressure up to MAWP without violating any safety limits. However, if the operating pressure does ever go over MAWP for any reason, the vessel should be checked and recertified. Management or supervision can never operate at a pressure exceeding MAWP without going through the MOC process.
4. Generally emergency systems such as interlocks and pressure relief valves will be set at a value just below MAWP.
5. If the internal pressure in a vessel continues to rise, then the walls will probably start to yield and around 2 times the MAWP. The vessel or associated piping may be slightly distorted, but any leaks are most likely to occur at gaskets. At this pressure it is likely that the vessel itself will not rupture.
6. At 2−4 times the MAWP, there will probably be distortion of the vessel and it can be assumed that gaskets will blow out. The vessel's burst pressure will typically be in the range of 3.5−4 times the MAWP. Therefore, for this example, the burst pressure would be in the 27−34 barg range. (It is difficult to predict this value accurately because so few vessels actually fail, so there is not much field data.)

Increased temperatures quickly reduce the strength of the steel. For example, the MAWP for a certain vessel may be 10 barg at a temperature of 300°C. At 550°C the same item may fail at just 1 barg (metal temperature refers to the average metal temperature through its entire depth). Therefore, each MAWP value must have an associated temperature.

Although low temperatures generally enhance metal strength (and so raise MAWP), very low temperatures may cause sudden and catastrophic embrittlement. This can be a serious problem in cryogenic services. For example, carbon steel equipment and pipe is liable to fail—even when there is no load on it—if its temperature falls below −20°C. This can occur, e.g., if a cryogenic liquid such as liquid air enters a carbon steel flare header.

TEST MEDIUM

The test medium can be either liquid (hydrostatic) or gas (pneumatic). Of the two liquid is strongly preferred, particularly for strength or hydrostatic tests. (Gas may be preferred for routine tightness tests since it is much simpler to use and there are fewer disposal problems once the test is complete.) The potential energy of a compressed gas is much greater than that for a noncompressible liquid. Hence, if the item were to fail, it could disintegrate violently. Pneumatic testing should only be used when hydrostatic testing is impractical—e.g., when testing a vacuum system that does not have the physical strength to support the piping when full of liquid.

Water is normally used as the test medium unless it could cause problems such as corrosion. The test water should be clean and should be of such quality as to minimize corrosion of the materials in the test system. If the equipment being tested is made of stainless steel, the chloride content of the water should not exceed 30 ppm. If water is not used, then the liquid selected must be a temperature below its boiling point. The use of combustible liquids should be avoided.

When liquid is used, the effect of its weight on equipment (particularly the bottom heads of large, tall vessels), their supports, and foundations must be carefully evaluated. One chemical plant, e.g., had large (72 inch) overhead lines coming from its vacuum columns. Because the normal operating pressure in those columns was very low, the wall thicknesses were correspondingly low and the structural supports were minimal. Had liquid been introduced into these overhead lines, they and the supporting structure would have collapsed—hence testing had to be carried out with high pressure gas.

TIGHTNESS TESTS

As discussed above, tightness test pressures should not exceed the equipment MAWP or system design pressure or the vessel's relief valve set pressure.

Once the system is at test pressure, it is held at that pressure for 15−20 minutes (1 hour maximum). If the pressure does not fall, then the system is tight. If the pressure does fall, then the leak must be found and repaired. Testing can be done using a soap solution if gas is being used as the testing medium. The solution is squirted on to the flanges that were parted and then put back together. Any gas leak will create bubbles in the solution.

STRENGTH TESTS

Nondestructive methods to determine thickness loss, which should be performed before conducting a strength pressure test.

If the vessel or piping has been modified in any way, then a strength test is required in order to ensure the vessel's integrity. Strength tests are conducted above the vessel's design pressure and above the set points of associated relief valves/rupture disks (which are either removed, blocked in, or have their valve disk clamped). A strength test must be conducted in accordance with the applicable codes and/or standards for which the equipment is constructed. For pressure vessels, the test pressure is 1.5 times the MAWP for ASME Section VIII, Division 1 vessels; 1.25 times the MAWP for Section VIII, Division 2 vessels; and 1.5 times the MAWP for Section I, Power Boilers. Systems designed for vacuum service should be strength tested at a pressure 1.5 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure. If the test is pneumatic, the test pressure may be lower than these values.

Vessels can be strength tested before being installed. However, piping is usually tested in the field. When testing a piping system attached to a pressure vessel, and it is not considered practicable to isolate the piping from the vessel, the piping and the vessel may be tested together.

TESTING PROCEDURES

The following points must be considered when establishing a pressure testing procedure (whether it be a tightness or strength test). The procedures to be followed will differ somewhat depending on whether the test medium is liquid or gas.

Hydrostatic (liquid)

- Some internal components, such as exchanger tube sheets, are only designed for the normal operating differential pressure. It is important not to apply higher than design differential pressure on them when applying test pressure to only one side of the item.
- If the test pressure could exceed the set pressure of a relief valve or rupture disk, then that device should be removed and/or blinded. The relief valve compression screw should not be adjusted.
- For most materials, the metal temperature for the strength test should be in the range 15°C–50°C throughout the duration of the test. (If the system is subject to thermal expansion or contraction, precautions should be taken to avoid excessive pressure or vacuum being created during the test.)
- Vents should be provided at all high points of the system to purge possible pockets of air or other noncondensible gases while the system is filling.
- Vents should be to open areas to avoid an accumulation of inert gases.
- No detailed inspection of the system should ever take place while it is at a pressure greater than the MAWP, and only the personnel directly involved with the test should be permitted within a 25-meter radius of the system being tested.
- Low-pressure filling lines and other appurtenances that should not be subjected to the test pressure must be disconnected or isolated.
- An indicating gauge, visible to the person controlling the pressure applied to the test system, should be connected to the system being tested. Hydrostatic head on the gauge should be considered. Dial pressure gauges used in testing should have dials graduated to about double the intended maximum test pressure, but always no less than 1.5 times that pressure.
- Pressure increase due to solar energy on the blocked-in liquid should be released.

Pneumatic (gas)

- Air should not be used in testing any system that contains hydrocarbons.
- A pressure relief device must be provided on the test apparatus having a set pressure not higher than 110% of the test pressure.

- The pressure should be gradually increased until a gauge pressure, which is the lesser of one-half the test pressure or 2 bar has been reached. This pressure should be maintained for at least 10 minutes. A preliminary check for leaks should be made. The pressure should be gradually increased in steps of approximately one-tenth of the test pressure and maintained for 10 minutes at each step until the required test pressure has been reached. Large systems can be tested in sections.

Installing blinds

When installing blinds, the following precautions should be considered:

- Check that the equipment or piping is prepared and properly released for blinding.
- Verify that correctly sized and rated blinds are to be installed.
- Verify that lines and equipment have been depressured and drained.
- Ensure that drain valves are open where available by using proper rod-out equipment.
- Determine what product or material has been contained in the equipment or piping. If this material is hazardous, secure and wear the appropriate protective clothing and equipment.
- If equipment to be blinded is above atmospheric pressure, ensure that the pressure is reduced to the lowest possible value.
- Wear protective clothing and personnel protective equipment as dictated by the circumstances. Always wear eye protection.
- Whenever possible, remove flange bolts on the side away from the workers, leaving a minimum of two, then loosen these bolts and without completely removing the nuts spread the flanges to install the blind.
- Always spread the flange on the side away from the workers first so any sudden release will be directed away from personnel.
- Flanges should be open a minimum length of time consistent with the safe installation of the blind.
- When opening flanges suspected to contain toxic gases, carry out an air quality check to determine the level of respiratory protection required for the task.
- Install blinds at the flange closest to the vessel, tank, or equipment under consideration.
- When vessels or process equipment is interconnected in such a way that blinding of each is not possible or practical, the combination is to be considered as one vessel. The combination will be appropriately blinded and prepared as a unit.
- A blind may have a gasket installed on both sides but a minimum of one gasket installed on the pressure side of the blind is required.

PRESSURE TEST MANUAL

In order to ensure that pressure tests are carried out correctly, a Pressure Test Manual can be developed. Table 2.2 provides a suggested Table of Contents for such a manual.

ONLINE CLEANING AND REPAIR

It is sometimes necessary to shut down parts of an operating facility for cleaning and repair after a long onstream period while the remainder of the facility continues in operation. Removal of the hazardous chemicals from equipment under these conditions requires careful planning. It is always best to assume that some hazardous chemicals remain trapped, even after the equipment has been cleaned.

The following precautions should be considered:

1. Water used to displace hydrocarbon in equipment must be overflowed or drained at a safe distance from all ignition sources, must be monitored for the presence of hydrocarbons, and must be disposed of in a suitable manner.
2. Ignition sources must be minimized during the purging process. For example, all hot work in the area should be stopped.
3. The vapor space of equipment prepared for repair must be tested to ensure that a safe level of hazardous material is present. This should be done before the equipment is opened.
4. Special procedures must be developed, where appropriate, to ensure that pyrophoric-iron sulfide deposits are safely removed.
5. When cleaning equipment that contains heavy hydrocarbon deposits and sludges, contingency plans must be developed to safely cope with the potential release of additional hydrocarbons or toxics into the atmosphere of the confined space when the sludge is disturbed.
6. If a confined space becomes hazardous after the tank or vessel has been opened and cleaning work is under way, workers should immediately leave the confined space.
7. Introducing steam into the atmosphere of a confined space that is within the flammable limits should be avoided as it may generate a static discharge.
8. Special equipment suitable for hydrocarbon detection must be used when the confined-space atmosphere to be measured has an oxygen content less than 10%. A special portable detector which operates on the thermal-conductivity principle or a laboratory Gas Chromatograph (GC) is preferred for these measurements.
9. All confined-space entry procedures (see Chapter 3) must be followed.

Industry guidance is provided in API Publication 2015—Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks (API, 2001), the Table of Contents for which is given in Table 2.3.

Table 2.2 Pressure Test Manual Contents

A. General
   1. Approval and documentation
   2. Purpose of test: strength or tightness
   3. Codes and standards
   4. Vacuum service systems
   5. Differential pressure testing
   6. Severe operating condition systems
   7. Brittle fracture precautions
   8. Test pressure exceeds RV setting
   9. High point vents
   10. Precautions for venting inert gas
   11. Work completion prior to strength test
   12. Detailed inspection precautions
   13. Thermal expansion precautions
   14. Pressure gauges used for testing

B. Hydrostatic strength test
   1. Approval procedures
   2. Potential catastrophic failure modes

C. Pneumatic strength test
   1. Restrictions for use/review/authorization
   2. Boilers
   3. Holding time for test pressure
   4. Use of air precautions
   5. Brittle fracture precautions
   6. Total volume/energy considerations
   7. Personnel precautions when testing
   8. Use of nonlubricated air compressors
   9. Test pressures for vessels/piping
   10. Pressure relief device requirement

D. Tightness test
   1. Use of air
   2. Testing equipment in groups
   3. Holding time for test pressure
   4. Brittle fracture precautions

E. Training
   1. Evaluating safety aspects for technical advice
   2. Evaluating recommendations for decision making
   3. Brittle fracture precautions
   4. Characteristics of liquids for hydrostatic testing
   5. Effects of added liquid weight
   6. Preventing pressure buildup in adjacent equipment
   7. Test pressures for vessels, boilers, and piping
   8. Personnel precautions when testing
   9. Holding time for test pressure

RV, Relief Valve.

Table 2.3 Contents for API 2015

1.	GENERAL
1.1	Scope and Applicability
1.2	Non-applicability and Other Tank Cleaning Applications
1.3	ANSI/API Recommended Practice 2016
1.4	Regulatory Requirements
1.5	Tank Cleaning Overview
2.	REFERENCES
2.1	Codes, Standards, and Related Publications
2.2	United States Government Regulations
2.3	Other Publications and References
3.	DEFINITIONS
3.1	General
3.2	Dentitions
4.	ADMINISTRATIVE CONTROLS AND PROCEDURES
4.1	General Requirements
4.2	Written Tank Cleaning Program
4.3	Qualified Persons
4.4	Training Requirements
4.5	Contractors
4.6	Tank Cleaning Equipment
5.	PREPARING THE TANK FOR ENTRY AND CLEANING
5.1	Initial Preparation
5.2	Typical Tanks
5.3	Decommissioning
5.4	Isolating the Tank
5.5	Control of Ignition Sources
5.6	Vapor and Gas Freeing, Degassing, and Ventilating
5.7	Initial Tank Cleaning
6.	TESTING THE TANK ATMOSPHERE
6.1	Atmospheric Testing Procedures
6.2	Atmospheric Testing Instruments
6.3	Atmosphere Testing
7.	STORAGE TANK HAZARDS
7.1	General
7.2	Oxygen Deficiency and Enrichment
7.3	Fire and Explosion Hazards
7.4	Toxic Substances
7.5	Physical and Other Hazards
8.	HAZARD ASSESSMENT FOR ENTRY PERMITS
8.1	General
8.2	Levels of Entry
8.3	Entry into Tanks Classified as Permit-Required Confined Spaces

(*Continued*)

Table 2.3 Contents for API 2015 *Continued*

8.4 Entry into Tanks Classified as Non-permit-Required Confined Spaces
8.5 Entry into Tanks Classified as Nonconfined Spaces
8.6 Entry for Assessment of Tank Condition
9. PERSONAL PROTECTIVE EQUIPMENT
9.1 Protective Clothing and Equipment
9.2 Respiratory Protection
10. TANK CLEANING PERSONNEL
10.1 General
10.2 Entry Supervisors
10.3 Entrants
10.4 Attendants
10.5 Qualified Persons
11. ENTERING AND WORKING INSIDE THE TANK
11.1 General
11.2 Entry Permit
11.3 Continuous Forced Air Ventilation
11.4 Tank Safe (Cold) Work, Maintenance, and Repairs
11.5 Undesirable Product, Sludge, and Residue Disposal
12. HOT WORK AND TANK REPAIRS
12.1 General
12.2 Hot Work Permits
12.3 Hot Work Hazards
12.4 Hot Work in Leaded Service Tanks
12.5 Fire Prevention
13. EMERGENCY PLANNING
13.1 Emergency Response Plan
13.2 Outside Rescue Services
13.3 Employer (Owner/Operator and Contractor) Rescuers
13.4 Rescue Equipment
13.5 Other Emergencies
13.6 Medical Emergencies
14. RECOMMISSIONING
14.1 General
14.2 Recommissioning Preparation
14.3 Refilling Tanks
14.4 Sampling and Gauging Tanks
14.5 Control of Ignition Sources
15. TRAINING
15.1 General
15.2 Qualification

INSPECTION

Inspection is a crucial part of any operating and maintenance system. It is vital that equipment and instrument items that could fail—particularly where that failure could lead to a safety or environmental violation—are monitored, and that corrective action is taken before problems arise.

Inspection programs for all types of equipment should include the following elements:

- Inspections to monitor the physical conditions of the vessels and columns and the type, rate and cause of corrosion, erosion, hydrogen blistering, stress cracking, or other deterioration.
- The use of internal corrosion coupons and gauge points installed as checkpoints for the inspector.
- The judicious use of corrosion inhibitors (when used at incorrect rates they can actually accelerate corrosion rates).
- Records of corrosion rates, mechanisms of corrosion, locations of corrosion, and inhibitors used.
- Information to do with equipment failures, maintenance, and repair methods.
- Inspection and maintenance records of the pressure relief valves and other pressure-relieving devices.
- Inspection of fireproofing systems.

Any small increase in wall thickness can be assumed to be attributable to measurement error. However, if the thickness continues to grow, or if a single measurement shows an unusually large increase (say more than 5% of a previous reading), then additional tests should be carried out.

REGULATIONS AND STANDARDS

API 510 (2006) lists the following 15 elements as part of an asset integrity quality control and inspection program:

1. Organization and reporting structure for inspection personnel
2. Documenting and maintaining inspection and quality assurance procedures
3. Documenting and reporting inspection and test results
4. Corrective action for inspection and test results
5. Internal auditing for compliance with the Quality Assurance Inspection Manual
6. Review and approval of drawings, design calculations, and specifications for repairs, alterations, and reratings
7. Ensuring that all jurisdictional requirements for pressure vessel inspection, repairs, alterations, and reratings are continuously met

8. Reporting to the authorized inspector any process changes that could affect pressure vessel integrity
9. Training requirements for inspection personnel regarding inspection tools, techniques, and technical knowledge base
10. Controls necessary so that only qualified welders and procedures are used for all repairs and alterations
11. Controls necessary so that only qualified nondestructive examination (NDT) personnel and procedures are used
12. Controls necessary so that only materials conforming to the appropriate pressure equipment codes are used for repairs and alterations
13. Controls necessary so that all inspection measurement and test equipment is properly maintained and calibrated
14. Controls necessary so that the work of contract inspection or repair organizations meet the same inspection requirements as the owner−user organization
15. Internal auditing requirements for the quality control system for pressure-relieving devices.

INSPECTION FREQUENCY

The frequency with which equipment items should be inspected will vary according to specific circumstances such as risk associated with the equipment, pertinent engineering standards, manufacturer's recommendations, and operating experience.

The following schedule was developed by (Sanders, 2004):

- Positive displacement pumps and compressors—12 months
- Vessels with corrosive chemicals—12 months
- Process vessels with heat or refrigeration sources—12 months
- Boilers (usually controlled by State law)—12 months
- Steam headers—24 months
- Storage vessels (clean)—24 months
- Instrument air manifolds—36 months
- Lubricating relief valves—36 months

The use of noninvasive inspection techniques has allowed substantial increases in shutdown intervals. When operating conditions are moderate it is possible to extend run times to as much as five years.

It is important to recognize that the act of inspection can itself cause reliability and integrity problems. For example, the BOEMRE Report on the Macondo incident (BOEMRE, 2011) provides the following quotation from someone involved in that event.

Taking BOP (blowout preventer) bodies completely apart, and say, checking the sealing areas of the gaskets. We found that by disassembling these areas, to do an inspection on them and then put them back together, we have more issues with them than after we disassemble them than we do before. I mean, we never had a problem.

INSPECTION RECORDS

The following minimum inspection records should be maintained.

- Date of inspection/test
- Name of inspector/tester
- Serial number of equipment
- Description of test
- Results of test

RISK-BASED INSPECTION

A risk-based approach to inspection helps ensure that resources are allocated as effectively as possible. RBI can be used for all kinds of equipment, including tanks, pumps, compressors, and pressure vessels. RBI is particularly helpful when planning a scheduled turnaround, where there is usually limited time, and managers must decide which items to inspect first.

Some of the discussion in the previous section to do with RCM that was provided above can also be applied to RBI programs.

RBI programs typically are divided into the following three parts:

1. Analyze risk
2. Determine the cost of equipment failures
3. Allocate inspection resources

An RBI assessment requires the active participation of a multidisciplinary group including, but not limited to, representatives from the following disciplines: inspection, metallurgy, process engineering, mechanical engineering, and operations. The discipline representatives must be thoroughly knowledgeable and experienced on the unit in their area of expertise. The assessment must be facilitated by a trained and knowledgeable RBI user.

Analyze risk

The first step is to define and quantify the risk of process equipment failure (safety, environmental, and economic), as discussed in Chapter 1. The risk analysis should include both the likelihood of failure of an equipment item and the consequences of such a failure. The analysis must consider all failure modes that could reasonably be expected to affect the piece of equipment in the particular service.

The evaluation of consequence should consider, as a minimum process fluid properties and operating conditions, and flammability, explosive, toxic, and environmental effects.

The evaluation of likelihood should consider the following, as a minimum:

- All forms of degradation that could reasonably be expected to affect a vessel in any particular service. Examples of degradation mechanisms include internal or external corrosion or erosion, all forms of cracking (both internal and external), fatigue, embrittlement, creep, high temperature, and hydrogen attack.
- The effectiveness of the inspection practices, tools, and techniques utilized for finding the expected and potential damage mechanisms.
- The materials of construction.
- The equipment design and operating conditions.
- Appropriateness of the design standards and codes used.
- The effectiveness of corrosion monitoring and control programs.
- Quality of maintenance and inspection activities and programs.
- Equipment failure history and data.

Information to do with risk can come from process hazards analyses.

SPARE PARTS

Well before commissioning starts, a sufficient supply of spare parts should be provided. Issues to consider include the following:

- The numbering system
- The need for maintenance training to do with installing the spare parts
- Storage requirements
- Inspection of spare parts
- Inventory control procedures

Determine costs

The next step is to analyze the cost of such failures in terms of safety, environmental violations, and overall business interruption, and determine what resources can be justified to reduce such failures.

Allocate resources

The final step is to allocate inspection resources to those equipment items which pose the highest risk to the facility.

CHAPTER

3 Energy control procedures

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00003-2

INTRODUCTION

The fundamental goal of any safety program is to ensure that workers are not exposed to sources of energy such as high-voltage electricity, high-temperature fluids, toxic chemicals, moving parts, or falls from heights. Therefore, before working on a piece of equipment, the associated sources of high energy must be identified and secured. In the case of a pump, e.g., the following energy sources are probably present:

- *Rotating energy*. The driver, drive shaft, and impeller all turn. It is important that they be secured from inadvertent movement (even if the motor has been de-energized) before anyone works on the pump.
- *Electrical energy*. If the pump has an electrically driven motor, the electricity supply to it must be properly isolated.
- *Heat energy*. If the pump is driven by a steam turbine, or if there is steam tracing around it, it is important to ensure that the steam—and the associated steam condensate system—are properly isolated.
- *Chemical energy*. If the pump normally handles hazardous chemicals that are toxic or a health hazard, it has to be properly cleared of them.
- *Flammable/explosive energy*. If the pump handles hydrocarbons, or other materials that could ignite, they have to be cleared, often using an inert gas such as nitrogen.
- *Potential energy*. If the pump is not located at grade, it may be possible for a person to fall off it (and if it is at grade there may be a pit below it.)

Energy control procedures can be placed into one of the four categories shown below (in the preferred order).

1. Removal of the hazard
2. Positive isolation of the hazard
3. Lockout/tagout of the hazard
4. Administrative controls

REGULATIONS AND STANDARDS

The following rules and standards can be used when developing energy control procedures and programs.

OSHA 29 CFR §1910.119

The OSHA standard and guidance to do with process safety and hot work is to be found in paragraph (k) of the regulation 29 CFR §1910.119—the process safety management standard.

In this standard the term "hot work," which really covers all types of permitted operations, is defined as follows:

Hot work means work involving electric or gas welding, cutting, brazing, or similar flame or spark-producing operations.

It provides the following rule and guidance:

RULE

(1) The employer shall issue a hot work permit for hot work operations conducted on or near a covered process.
(2) The permit shall document that the fire prevention and protection requirements in 29 CFR 1910.252(a) have been implemented prior to beginning the hot work operations; it shall indicate the dates authorized for hot work; and identify the object on which hot work is to be performed. The permit shall be kept on file until completion of the hot work operation.

GUIDANCE

Non routine work which is conducted in process areas needs to be controlled by the employer in a consistent manner. The hazards identified involving the work that is to be accomplished must be communicated to those doing the work, but also to those operating personnel whose work could affect the safety of the process. A work authorization notice or permit must have a procedure that describes the steps the maintenance supervisor, contractor representative, or other person needs to follow to obtain the necessary clearance to get the job started. The work authorization procedures need to reference and coordinate, as applicable, lockout/tagout procedures, line breaking procedures, confined-space entry procedures, and hot work authorizations. This procedure also needs to provide clear steps to follow once the job is completed in order to provide closure for those that need to know the job is now completed and equipment can be returned to normal.

The standard cross-references 29 CFR §1910.252(a), which is the provision of the Welding, Cutting, and Brazing Standards dealing with fire prevention and protection. It also refers to the NFPA (National Fire Protection Association) Standard for Fire Prevention in Use of Cutting and Welding Processes (51B, 1962).

One of NFPA's principle concerns is to do with the isolation of hot work from flammable materials. The following steps must be followed:

(1) Remove the object to be welded or cut to a safe place, i.e., away from the flammable materials.
(2) If (1) cannot be done, remove the flammable materials to a safe place.
(3) If (2) cannot be done, place guards around the work to prevent heat, sparks, and slag from reaching the fire hazard.
(4) If (3) cannot be done, the work shall not be performed.

While the work is being performed, fire extinguishers must be in place, and a fire watch shall be maintained.

OSHA 29 CFR §1910.146

The OSHA standard *Permit-required confined spaces* (OSHA 2009) provides detailed guidance to do with the management of confined-space entry. Taylor (2011) discusses some of the problems of interpretation that can crop up when using the OSHA standard.

API 2015

API Standard 2015—Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks—provides guidance on vessel entry in general. Its Table of Contents was provided in Chapter 2.

API 2026

API 2026 is entitled Safe Access/Egress Involving Floating Roofs of Storage Tanks in Petroleum Service, 2001. The Table of Contents is given in Table 3.1.

API 2217A

API Standard 2217A—Guidelines for Work in Inert Confined Spaces in the Petroleum and Petrochemical Industries (2009). Its Table of Contents is provided in Table 3.2.

ANSI Z117.1

ANSI's *Safety Requirements for Confined Spaces* provides minimum safety requirements to be followed while entering, exiting, and working in confined spaces at normal atmospheric pressure. The Table of Contents for the standard is given in Table 3.3.

A detailed analysis of the standard is provided by the MSA Company (MSA 2009).

REMOVAL OF THE HAZARD

As discussed in Chapter 1, the best way of mitigating any type of risk is simply to remove the hazard. This philosophy most certainly applies to energy control procedures. For example, if it is necessary to clean out the inside of a storage tank, it is safest to completely drain the tank of chemicals, remove any solid materials such as sludge or scale, and then purge it with air until the atmosphere in the tank is safe to breathe. Doing so is much safer than having the workers wear special breathing equipment while the hazardous chemicals are still in the tank.

Table 3.1 Contents for API 2026

1. SCOPE AND OBJECTIVES
    - 1.1 Scope
    - 1.2 Objectives
2. REFERENCED PUBLICATIONS
3. DEFINITION OF TERMS
4. GENERAL PRECAUTIONS FOR DESCENT ONTO FLOATING ROOFS
    - 4.1 General Conditions
    - 4.2 Permit Space Program Requirements
    - 4.3 Requirements for Descent Onto Floating Roofs
5. POTENTIAL HAZARDS ASSOCIATED WITH ENTRY UPON FLOATING ROOFS
    - 5.1 General Atmospheric Testing Requirements
    - 5.2 Potential Oxygen Content Hazards
    - 5.3 Potential Flammable Vapor Hazards
    - 5.4 Potential Toxic Vapor and Gas Hazards
    - 5.5 Potential Vapor Exposures
    - 5.6 Potential Fire Hazards
    - 5.7 Potential Physical Hazards
6. PREPARATION FOR ENTRY UPON FLOATING ROOFS: VENTILATION, TESTING, AND RESCUE
    - 6.1 Ventilation Requirements
    - 6.2 Atmospheric Testing Requirements
    - 6.3 Emergency Rescue Planning
7. PROCEDURES FOR DESCENT ONTO OPEN-TOP FLOATING ROOFS
    - 7.1 General
    - 7.2 Preparations Prior to Descent Onto Open-Top Floating Roofs
    - 7.3 Initial Descent Onto Open-Top Floating Roofs
    - 7.4 Working on Open-Top Floating Roofs of Tanks in Service
    - 7.5 Permissible Work on Open-Top Floating Roofs
8. PROCEDURES FOR DESCENT ONTO INTERNAL AND COVERED OPEN-TOP FLOATING ROOFS
    - 8.1 General
    - 8.2 Preparations Prior to Descent Onto Internal and Covered Open-Top Floating Roofs
    - 8.3 Initial Descent Onto Internal and Covered Open-Top Floating Roofs
    - 8.4 Working on Internal and Covered Open-Top Floating Roofs of Tanks in Service
    - 8.5 Permissible Work on Internal and Covered Open-Top Floating Roofs

Sometimes, ensuring that a hazard has been completely removed can be difficult. For example, when cleaning out a tank, it is difficult to ensure that no pockets of hazardous chemical remains in corrosion pockets in the metal wall or at between the wall and the tank base.

Table 3.2 Contents for API 2217A

1. SCOPE
2. REFERENCES
3. DEFINITIONS
4. ADMINISTRATIVE CONTROLS
   - 4.1 Written Procedures and Guidelines
   - 4.2 Entry Supervisor
   - 4.3 Contractors
5. HAZARDS
   - 5.1 General
   - 5.2 Oxygen Deficiency
   - 5.3 Fires and Explosions
   - 5.4 Pyrophoric Hazards
   - 5.5 Physical Hazards
   - 5.6 Toxic Substances
6. PRE-ENTRY CONSIDERATIONS
   - 6.1 General
   - 6.2 Permits
   - 6.3 Inert Gas Source
   - 6.4 Lockout/Tagout
   - 6.5 Ignition Sources
   - 6.6 Radiation Sources
   - 6.7 On-Site Conditions
   - 6.8 Heat Stress
   - 6.9 Testing and Monitoring
7. PERSONAL PROTECTION
   - 7.1 General
   - 7.2 Respiratory Protection
   - 7.3 Clothing
   - 7.4 Communications
   - 7.5 Attendant(s) Responsibilities
   - 7.6 Entrant(s) Responsibilities
   - 7.7 Emergency Rescue Equipment
   - 7.8 Rescue and Emergency Services
8. OTHER CONSIDERATIONS

EQUIPMENT AND PIPING

The risks to do with working on energized systems can be reduced by designing equipment and piping to be more inherently safe. Some ways of doing this are discussed in the following sections.

Table 3.3 Contents for ANSI Z117.1

1. Scope, Purpose, and Application of Standard
   - 1.1 General
   - 1.2 Scope
   - 1.3 Purpose
   - 1.4 Application
2. Definitions
3. Identification and Evaluation
   - 3.1 Confined Space Survey
   - 3.2 Hazard Identification
   - 3.3 Hazard Evaluation
   - 3.4 Confined Space Classification
   - 3.5 Hazard Re-evaluation
   - 3.6 Written Program
4. Non-Permit Confined Space (NPCS)
   - 4.1 Controls
   - 4.2 Training
   - 4.3 Re-evaluation
   - 4.4 Atmospheric Testing
5. Permit Required Confined Spaces (PRCS)
   - 5.1 Entry Permits
   - 5.2 Permit Implementation
   - 5.3 Duration of Permits
   - 5.4 Revoking Permits
   - 5.5 Changing Work Conditions
6. Atmospheric Testing
   - 6.1 Requirements
   - 6.2 Testing Considerations
   - 6.3 Acceptable Limits
7. Entry Team
   - 7.1 Attendant
   - 7.2 Entrant
   - 7.3 Attendant(s)/Entrant(s) Communication
   - 7.4 Entry Supervisor/Leader
8. Isolation and Lockout/Tagout
   - 8.1 General
   - 8.2 Isolation
   - 8.3 Lockout/Tagout
9. Ventilation
   - 9.1 Requirements
10. Cleaning/Decontamination

(*Continued*)

Table 3.3 Contents for ANSI Z117.1 *Continued*

11. Personal Protective Equipment (PPE)
    - 11.1 General
    - 11.2 Selection
    - 11.3 Inspection
12. Auxiliary Equipment
    - 12.1 Entry and Exit
    - 12.2 Retrieval Equipment
    - 12.3 Fall Protection
    - 12.4 Electrical Equipment
13. Warning Signs and Symbols
    - 13.1 Identification
14. Emergency Response
    - 14.1 Emergency Response Plan 36
    - 14.2 Atmospheric Monitoring
    - 14.3 Respiratory Protection Equipment
    - 14.4 Rescue Equipment Inspection.
15. Training
    - 15.1 General Requirements
    - 15.2 Training for Atmospheric Monitoring Personnel
    - 15.3 Training for Attendants
    - 15.4 Training for Emergency Response Personnel
    - 15.5 Verification of Training
16. Medical Suitability
17. Contractors
    - 17.1 Hazard Appraisal
    - 17.2 Identification of Rescue Responder
    - 17.3 Permit System
    - 17.4 Coordination
    - 17.5 Ongoing Dialogue

VENTING AND DRAINING REQUIREMENTS

- Equipment and systems, provided with isolation for servicing, should be equipped with vent and drain valves as required to relieve pressure and remove fluids from the isolated equipment.
- Isolated components containing high pressure or a significant volume of vapor should be equipped with a vent valve. If the potential exists for venting of a significant volume of vapor the vent should be tied into the appropriate flare or vent system. For high-pressure services, the vent should include a throttling valve in addition to the isolation valve to control the rate of venting.
- Isolated components containing a significant volume of liquid should be equipped with a drain valve. If the volume of liquid is large, the drain should

include a throttling valve in addition to the isolation valve to control the rate of draining and to prevent large volume gas blow by to the drain system.

MANWAYS

When removing the first manway, the following guidelines can be used:

- Loosen bolting on the manway and remove all but four bolts. These are at the 12, 3, 6, and 9 o'clock positions.
- The last bolts on the manway should be loosened and carefully spread open to ensure that there is no pressure trapped in the vessel.
- When it is confirmed that there is no residual pressure in the vessel, the four bolts can be removed, and the manway taken off.

ELECTRICAL EQUIPMENT

Electrical equipment can be isolated as follows:

- Shut down the equipment using the selector switch followed by the master disconnect.
- Ensure that all power sources are locked and tagged out.
- Stored electrical energy must be discharged to obtain zero energy state.
- When working on or near exposed de-energized electrical equipment, a qualified person should use test equipment to ensure that all circuits are dead.

MECHANICAL EQUIPMENT

- Release or block all stored mechanical energy including that contained in springs and items under tension.
- Use blocks, pins, or chains to restrain energy when equipment cannot be brought to a zero potential energy state.
- Padlocks, lockouts, blinds, and tags should be used to lockout and tagout mechanical energy.
- If additional energy sources are present, follow the applicable methods of energy isolation listed in this section.

PIPE PLUGS

Plugs are sometimes used in pipeline repair; they create a vapor barrier when a line has been isolated and depressured, but has not been completely cleared of flammable, combustible, or toxic materials. Expandable plugs are also used to isolate sections of gravity drain systems such as sewers. Examples include plumbers plugs—which consist of two parallel disks that compress an elastic material together to form a seal on the inside diameter of the pipe—and inflatable bladders—which are inflated either pneumatically or hydraulically inside the pipe much like a balloon. They are often used to isolate sections of gravity drain systems such as sewers.

Because they do not hold any significant pressure, expandable pipe plugs should be equipped with a connection to allow venting of the upstream side of the plug. Vents and drains on the line side of the plug must be open and adequate to prevent overpressure from expelling the plug from the piping.

The following precautions should be considered when using pipe plugs:

- Inflatable bladders must be equipped with a pressure gauge indicating internal pressure, which should be verified prior to initiating work.
- A grounding lead should be installed across the sections of piping to be parted. Install a grounding lead from the pipe to the plumbers plug after it is inserted.

MINIMIZING CONTACT WITH AIR

When working with flammable hydrocarbons, if it is not possible to remove the flammable materials themselves, then air/oxygen should be removed from the item that is to be worked on in order to avoid the creation of an explosive mixture or a flammable cloud.

LIMITING OXYGEN CONCENTRATION

All materials have a limiting oxygen concentration (LOC). If the oxygen content in the vapor space above the liquid being stored is below the LOC, then the vapor space is not flammable. The values given in Table 3.4 are LOC values for commonly used chemicals. They are taken from NFPA 69 (2014), the Table of Contents for which is given in Table 3.5.

BLANKETING

One of the most effective ways of minimizing problems with hazardous liquid—particularly flammable liquids—is to blanket them with an inert gas. This policy is particularly pertinent with regard to storage tanks because the fuel and air are always present, and static electricity as an ignition source is very difficult to

Table 3.4 Limiting Oxygen Values

Material	LOC, vol. % O_2
Propylene oxide	5.8
Methanol	8.0
Ethanol	8.5
Acetone	9.5
Benzene	10.1
Vinyl chloride	13.4

Table 3.5 Contents of NFPA 69

Chapter 1 Administration
- 1.1 Scope
- 1.2 Purpose
- 1.3 Application
- 1.4 Retroactivity
- 1.5 Equivalency

Chapter 2 Referenced Publications
- 2.1 General
- 2.2 NFPA Publications
- 2.3 Other Publications
- 2.4 References for Extracts in Mandatory Sections

Chapter 3 Definitions
- 3.1 General
- 3.2 NFPA Official Definitions
- 3.3 General Definitions

Chapter 4 General Requirements
- 4.1 Goal
- 4.2 Objectives
- 4.3 Compliance Options

Chapter 5 Performance-Based Design Option
- 5.1 General Requirements
- 5.2 Performance Criteria

Chapter 6 General Prescriptive Requirements
- 6.1 Methods
- 6.2 Limitations
- 6.3 Factors to Be Considered
- 6.4 Plans
- 6.5 System Acceptance
- 6.6 Inspection and Maintenance
- 6.7 Housekeeping

Chapter 7 Deflagration Prevention by Oxidant Concentration Reduction
- 7.1 Application
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eliminate, so the only control option is to remove the oxygen by blanketing the tank with an inert gas.

Nitrogen is the most frequently used (Yanisko et al., 2011) blanketing gas. Carbon dioxide can be used but is not quite as inert; argon is totally inert but is considerably more expensive than nitrogen. A nitrogen blanket can also help with health and environmental issues, e.g., by keeping products in the food and pharmaceutical industries from becoming contaminated.

TANK FILLING AND EMPTYING

A discussion to do with the design of storage tanks is provided in Chapter 12. Some operational issues are discussed below:

- When fixed roof tanks with an open vent are filled, hydrocarbon or chemical vapors are discharged into the air, thus creating a fire hazard. To eliminate this hazard, the vent can be connected either to a vapor recovery system or to other tanks through an interconnecting vapor system where liquid is being drawn out of these interconnected tanks at a rate sufficient to make space for the vapor being displaced from the filling tank.
- When fixed roof tanks are being emptied, air can enter the vapor space. If this is not safe, the tank should be padded with a gas that is either inert or compatible with the liquid contents (flue gas or natural gas are sometimes used). The gas must enter the tank at a sufficiently high rate to avoid creating of a vacuum, with the possibility of pulling in the tank.
- When emptying floating roof tanks, “landing the legs” will create a vapor space above the liquid, thus causing air to be drawn in through the roof seals.

The resulting atmosphere may be in the flammable range. Therefore, the only time a roof should be set down on its legs is when the tank is to be taken out of service.

HEAVY SLUDGE DEPOSITS

Some atmospheric storage tanks and process vessels in heavy hydrocarbon service (e.g., crude storage tanks, coker fractionators, crude and vacuum towers) may contain heavy sludge and coke-like deposits. Demister pads and coalescers may also contain similar deposits. These heavy materials can be difficult to remove.

The following options for removing these materials should be considered:

- Cutter oil that dissolves the sludge deposits may be effective.
- Firewater can be added to tanks. The sludge may dissolve, become dispersed in, or float on top of the water. The water/sludge mix is then removed by a vacuum truck and the sludge is removed by filtration.
- Heavy sludge can also be removed by steaming it out. (In towers where coke may be present with high boiling point, hydrocarbons can be trapped within the coke pores and will not vaporize with steaming.)
- Hot water or boiler feedwater is sometimes more effective than steam at removing heavy sludge deposits. The hot water tends to wash out waxy solids. If used for cleaning a distillation column or tower, the water can be circulated through the reflux piping.

SPILLS AND OVERFLOWS

Spills or overflows that occur while filling containers, drums, trucks, or tanks will create a fire hazard. If such a spill should occur, prompt action is necessary to remove possible sources of ignition such as automotive engines. If the spill occurs adjacent to fired heaters or other static ignition sources, then consideration should be given to shutting them down until the spill has been cleaned up and/or foam has been applied to the spilled materials.

FLAME PROPAGATION THROUGH DRAINS

Fires can spread by the propagation of flame through flammable vapor—air mixtures in sewers and drains. It is very important to ensure that flammable materials are not allowed to enter drains and also to avoid hot work around open drains. Sewers should be water sealed to prevent release of vapor near fired equipment and to prevent the propagation of flame from one area into another.

CATCHING SAMPLES

Drawing liquid hydrocarbon samples from process equipment will expose small quantities of the material to air, thus potentially creating a flammable vapor mixture. Similarly, draining water from the bottom of a hydrocarbon tank to an open drain is likely to allow some hydrocarbon to be exposed to air before the drain valve can be closed. In cases such as these, the following precautions should be considered:

- Operators should stand where they can immediately shut off the flow of liquid if a fire or large spill should occur.
- If self-closing valves have been provided, these should never be blocked or tied open.
- An open valve should never be left unattended.
- All open-end connections should be plugged when not in use.
- The amount of sample flush should be minimized and all flush should be routed to an appropriate safe collection system or location.

If the distance between the body of the material to be sampled and the sample point itself is long, thus requiring a long flush time, a circulation loop should be set up as shown in Figure 3.1. Normally valves A and B and the sample valve are closed. When a sample is to be taken, A and B are opened for a sufficient period of time to allow fresh material to flow through the sample circuit. The sample valve is then opened and the sample caught (in a bottle for liquids and a sample bomb for gases). Then all three valves are returned to the closed position. It is important not to leave A and B open because otherwise the control valve will not be able to fully stop the flow of fluid during normal operations. Also, if they are closed and the sample valve is opened by mistake, not much liquid will escape.

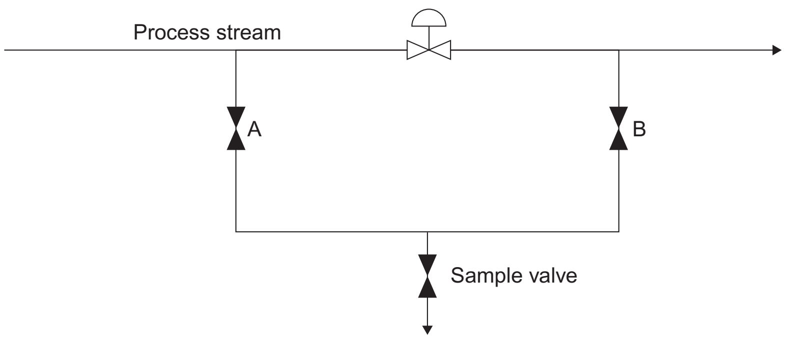

FIGURE 3.1

Sample valve flush.

AIR-BLOWING OF HYDROCARBON LINES

When air is used to clear a line that had contained hydrocarbons, the potential for forming a flammable mixture of air with hydrocarbon vapors and/or mist is created. The elevated pressure which can be developed in a line or system broadens the flammable range, lowers the autoignition temperature, and can convert a previously fuel-rich mixture into a flammable mixture by lowering the vapor mole fraction of the fuel. Even though the temperature of a hydrocarbon liquid in a line may be below its flash point, mist formation can occur due to the sparging action of the air and can result in a flammable quantity of material being forced into the vapor space.

Only a very thin film of oil is needed to produce an explosion in the pipework of compressed-air systems, even if the oil is not dispersed into the air prior to ignition. Many industrial fires and explosions have occurred in systems utilizing oil-lubricated air compressors. Therefore, adding air to an "empty" hydrocarbon line, or to purge a hydrocarbon line, is potentially hazardous because trace amounts of flammable materials may be clinging to the pipe walls. On one occasion, an explosion occurred in a crude-oil pipeline to which air had been added, even though the line had been first "emptied" by displacement with water between two scraper plugs.

Although autoignition is the probable cause of ignition in most compressed-air-line fires, other sources are possible. They include heat generated by the oxidation of iron sulfide, other sulfur compounds or carbonaceous deposits which may unexpectedly be present in the line, and friction or static-electricity-generated sparks.

POSITIVE ISOLATION

Positive isolation methods are those which remain effective even if there is equipment failure or operator error. These techniques apply not only to vessels, piping, and tanks but also to pneumatic and hydraulic equipment.

Figure 3.2 shows some of the various isolation techniques that can be used to protect workers in the process industries. The process containing toxic or flammable chemicals under pressure is on the left; the open system, where the workers are present, is on the right. The order is from the least to the most secure.

LEVEL 1—CLOSED VALVE

The use of a single closed valve is rarely acceptable as a means of isolation in the process industries—except in the most benign services—for two reasons. First, it is very easy for someone else to inadvertently open the valve. Second, the closed valve may leak.

One company places the following conditions on the use of a single block valve to provide isolation:

- The isolation block valve closes tight and does not leak
- It is locked closed and tagged

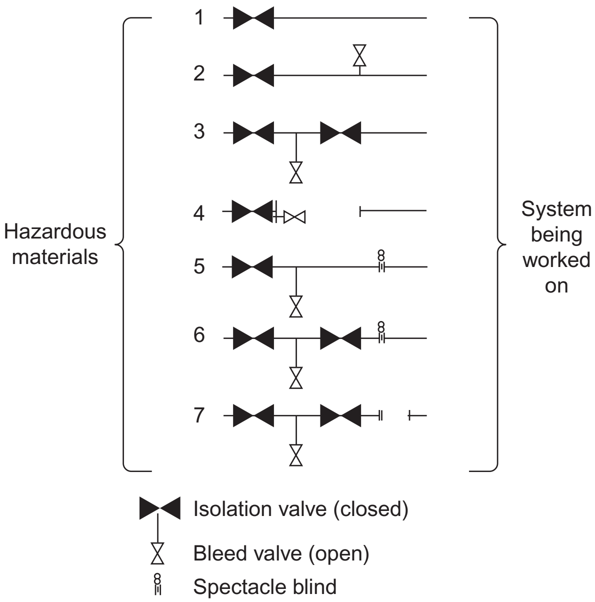

FIGURE 3.2

Isolation methods.

- The job is continuous and uninterrupted
- The work is conducted during daylight hours
- No confined-space entry or hot work is involved

If a valve is to be used for isolation, it should generally be a gate, ball, plug, or needle valve. In some instances, butterfly valves are allowed in nonhazardous services. Where actuated valves are used, the actuator mechanism must be isolated from all possible supply sources. Check valves, control valves, and relief valves are not acceptable as isolation devices.

Types of valve that can be used for single-valve isolation include gate, ball, plug, and needle. Butterfly valves may be allowed in nonhazardous services. Valves specified for control or throttling service (choke or control valves) should not be used for isolation. Check valves and relief valves are not acceptable for designing means of isolation. In all cases, the valves chosen must be designed to provide a positive shutoff seal for the inventories and pressures involved.

If actuated valves are used, then the actuator mechanism must be isolated from all possible supply sources before work commences and before the valve can be considered secure.

Special issues to do with various types of valve are discussed in the following sections.

Control valves

If it is necessary to perform maintenance on a control valve, and if it has a bypass that can be used to maintain process flow, single isolation with a mechanical isolation on either side of the control valve is acceptable, as long as:

- The isolation valves and the manual bypass/dual control valves are rated for the maximum design pressure and the control can be maintained by either manually operating the bypass valve or automatic control of the dual control valve in parallel, and an isolation risk assessment has been performed.
- If this is not the case, the system must be isolated in order for the control valve to be serviced. The system, which has a control valve with no bypass or dual valve in parallel, will have to be isolated to work on the valve.
- The control valves themselves are not considered as isolation valves for system or component isolation.

Blowdown valves

Blowdown valves (BDVs) are used to depressurize a system or component in order to carry out maintenance work or if there is an emergency. The BDVs require a downstream isolation valve, with a bleed between the two. In the case of remedial work, once the pressure has been relieved, the downstream isolation valve will be closed, and a blind will be installed upstream of the BDV.

If the BDV itself requires maintenance then the upstream equipment or system will be depressurized, the BDV downstream isolation valve will be closed, the BDV will be removed, and blind flanges will be installed on both open-ended flanges. The system will remain shut down until the BDV is reinstalled and certified in functional working order.

BDVs themselves are considered as isolation valves for system or component isolation.

Shutdown valves (offshore)

On offshore facilities shutdown valves (SDVs) are generally part of a system boundary. If SDVs in high risk areas require maintenance the associated system will have to be shut down. For lower risk operations shutting in the downstream isolation valve, as well as an upstream valve will be sufficient. The SDVs require an upstream isolation valve, with a bleed, if the valve is part of the inlet system boundary, and a downstream isolation valve and bleed between the two, if the SDV is part of the outlet system boundary. The only exception to this is the gas lift and gas injection boarding valves, which require isolation valves on both sides of the SDVs.

The gas lift and gas injection boarding valves require close monitoring to ensure a positive shutoff. These valves may be required, by government regulations, to be tested for positive shutoff, on a regular basis. Due to this requirement, isolation valves will be required on each side of these SDVs. Vents will also be installed before the upstream isolation valve. Subsea landing valves will also be required at the bottom of each departing riser from these lines. This will help to reduce the gas inventory. If one of these boarding valves requires work, the gas lift injection or gas injection well will be shut in. The pressure will be bled off around the SDV and on either side of the SDV isolation valves, through the vent line to flare. Both isolation valves will be closed, and the bleed opened between them. With pressure bled off around the SDV and on both sides of the isolation valves, the SDV will be removed, and blinds installed on each open flange.

The SDVs themselves are considered as isolation valves for system or component isolation.

LEVEL 2—CLOSED VALVE WITH OPEN BLEEDER

The open bleed/vent valve represents a low-pressure spot in the system. Therefore, if there is a release through the closed block valve, the hazardous materials will bleed off before entering the equipment being worked on. If the discharge from the bleed/vent line could itself be hazardous, it can be routed to a safe location, such as a flare header.

If the hazardous chemical is a liquid, the bleed valve should point downward; if it is a vapor, then the bleed valve should point up.

LEVEL 3—DOUBLE BLOCK AND BLEED

A double block and bleed system is widely used in the process industries. It uses two closed block valves with a bleed valve between them. The bleed valve can be used to check for leakage through the root isolation valve and/or to route leakage to a safe containment system. The pressure in the section of pipe between the two block valves should be zero.

Double block and bleed would not generally be considered acceptable for confined-space entry.

Use of a double block and bleed valve arrangement should only be used when blind flanging is impractical and it can be verified that the double blocks do not leak. When using this approach, careful consideration must be given to:

1. The ability to reposition the valve(s) under locked conditions, should the block and bleed arrangement show signs of leaking.
2. The ability/potential to inadvertently override electrical lockouts.
3. Normal failure modes of in-line instrumentation.
4. Prior history of isolation equipment (block valve, check valve, etc.) failures.

Double block and bleed isolation can be achieved through the use of any two appropriately located valves in the system, even though the valves may also serve other functions. Actuated isolation valves can be used in double block and bleed arrangements if means are provided to defeat automatic operation of the valves. Single body, integral double block and bleed valves can also be used, particularly in space-restricted areas.

It is necessary to ensure the integrity of both block valves/barriers. For a conventional arrangement using two block valves, this can be achieved by isolating and proving the downstream block valve first. In the case of a single body integral double block and bleed valve, the bleed port must be suitable to allow pressurization of the cavity for testing of the downstream seal, as well as allowing bleed off to test the upstream seal.

The conventional method to provide double block and bleed isolation is to provide two valves with a spool piece between them. The spool piece has a small bleed valve attached to it so that when the two main valves are closed, the small bleed valve can be opened to bleed off pressure between the valves to determine if the two valves are sealing properly.

There are several valves on the market that can provide this double block and bleed capability in one valve. Important note: many valves, ball valves in particular, are advertised in vendor literature as having double block and bleed capability. However, only a few of them provide a true double block with line pressure upstream of the valve and atmospheric pressure downstream of the valve.

LEVEL 4—BLOCK AND BLEED WITH LINE BREAK

The key difference between this system and the double block and bleed is that the line connecting the hazardous chemicals to the place of work has a section removed. Therefore there is no way that the chemicals can transit directly to the workers' location. The bleed valve is left open so that the workers know if the closed root block valve has started leaking. It can be attached directly to the valve as shown, or it can be attached to the line leaving the block valve.

A grounding lead should be installed across the sections of pipe that have been parted to protect against stray currents generating a spark. These currents could be generated by energy sources that have not been properly de-energized, such as cathodic protection of the pipe system or nearby equipment.

LEVEL 5—BLOCK, BLEED, AND SPECTACLE BLIND

Line blinding, which is often done in conjunction with the other methods, requires that a flat piece of metal be bolted to the flange at the end of the exposed line. The blind should be rated to take full line pressure plus the appropriate safety margins. In order to check that a blind is in place, it usually has a short handle which juts out from between the flange faces.

Blinding must be done if any of the following conditions exist:

- Whenever it is not possible to positively verify that the cavity between double blocks is at zero energy state.

- Whenever the system is open and personnel are not physically on scene and in control of the double blocks. System components might include pipelines, valves, strainers, meters, pumps, heat exchangers, and air eliminators.
- Double block and bleed valve arrangement is not permitted as an isolation device when working in permit-required confined spaces.

The following considerations apply to the use of blinds:

- Effectiveness in the selected location
- Verification of the blind's pressure rating
- Safe removal of the blind
- Safe accessibility for personnel and equipment
- Located at the flange closest to the equipment, tank, or vessel
- The blind must be stamped with its pressure rating and type
- Potential for exposure to toxic or corrosive material

There are two problems to watch for with blinds. The first is to make sure that it they are specified correctly. There have been numerous incidents where blinds of too low a pressure rating have buckled when exposed to full system pressure.

The second problem concerns accidentally forgetting to remove blinds when the work is over. During a large turnaround, there may be hundreds of blinds installed in the system. As the maintenance work closes out, there is usually considerable pressure to get the plant up and running as quickly as possible. It is all too easy to overlook a blind, then, when the plant is started, it will be found that the blinded line cannot be operated. The removal of the blind at this time can be hazardous, particularly as there is likely to be a lot of management pressure to keep the start-up moving and process conditions may already mean that temperatures and pressures are high.

Blinds should be installed to effectively isolate equipment, vessels, and piping from other parts of operating areas so repairs, maintenance, or cleaning can be conducted in a safe manner. Disconnecting a line and blinding off with a vice clamp and cap is an appropriate method of low-pressure equipment isolation; however, it is imperative that the cap be installed to prevent migration of vapors into the vessel or tank.

LEVEL 6—DOUBLE BLOCK AND BLEED WITH BLIND

This system adds a layer of protection to the standard block and bleed. Were any materials to travel through the closed block valves, the workers would still be protected by the presence of the blind.

LEVEL 7—DOUBLE BLOCK AND BLEED WITH LINE BREAK

This system provides a very high degree of protection. Any leak through the root valve is diverted through the bleeder—and there is no way that hazardous chemicals can cross the line break.

LOCKOUT/TAGOUT

Lockout/tagout systems are routinely used to protect workers when they are working with or close to hazardous systems. They are routinely used in conjunction with the other isolation methods. Once a switch or valve is in the correct position it is locked so that it cannot be moved, and a "Do Not Operate" tag is attached to it. (Valves are often chained in place, with the lock being used to secure the chain such that the valve handle cannot be moved.)

In spite of the security that a lockout system provides, it is less safe than the use of positive isolation methods. First a valve may leak while it is in the closed position. Second, in spite of all precautions, someone may remove the lock before the work has been finished. There is also a chance of confusion; the wrong valve may be chained closed, while the valve that should have been secured is left in its normal operating state.

Lockout/tagout is not normally used for routine operating activities such as collecting samples, replacing pressures gauges, or making equipment checks and adjustments. However, it is used on some systems in normal operation, e.g., pressure safety valves locked open or containment drain valves locked closed. Similarly, lockout/tagout is not used for plug connections on electrical equipment because the hazard can be controlled simply by unplugging the equipment. (However, the plug that has been detached must be properly controlled so that no one inadvertently puts it back in the socket.)

Lockout/tagout does not normally apply to handheld power tools or stationary equipment whose electrical power may be controlled by the unplugging of equipment from the energy source when the plug and cord are under the control of the employee performing the servicing or maintenance.

Once the system has been prepared for work, and the locks have been applied, the system must be verified. If it is a motor that is being worked on, e.g., the area should be cleared in case the isolation procedures fails, and then an attempt should be made to run the motor. If it is a valve that is being locked closed, the safety lead should try to open it after the locks and chains have been applied. Some companies use the phrase *lock, tag, and verify* to describe this process.

GROUP LOCKOUT

When more than one person is working on a job, a group lockout/tagout procedure is needed—one in which each person involved can apply their own lock, and only they can remove it (sometimes known as a Masterlock system). Details vary from company to company, but the following process is representative.

- The lead person on the job locks each valve, switch, and any other device that is used to isolate the high-energy source. Only the lead has a key to these locks.

- He or she labels the locks with the appropriate work permit information and then attaches a lockbox to each location.
- He places the keys in the box, closes it, and then locks it with a master lock (which is often a distinct color such as red.)
- Every worker who is to work on that job attaches his or her lock to the lockbox. They record what they have done on the work permit.
- If a worker leaves the job, he or she removes their lock and signs off on the work permit.
- If there is a shift change, workers on the first crew must sign off the job and remove their locks, and workers on the second crew must sign on to the job and add their locks.
- At the end of the job, each worker removes his or her locks and signs off. Each person must satisfy themselves that the job has, from their point of view, been returned to a safe condition before they remove their personal lock.
- The lead then removes the master lock and takes the keys from the open box.
- He then closes the work permit, and unlocks the valves or switches, which is now safe to operate.

LOCKBOXES

Lockboxes may be used when multiple individuals' locks would be required, or in order to avoid the use of multiple locks per authorized individual (i.e., each authorized individual locking several pieces of equipment). The use of a lockbox will be managed as follows: the methods and devices listed below will be used either separately or in combination, depending on the equipment, to lockout/tag-out the following energy source(s):

- An authorized employee will perform the isolation of the work area and involved equipment and complete the lockout permit.
- All keys involved in the lockout of equipment will then be placed in the lockbox.
- The authorized individual will install an individually keyed lock on the lockbox. His or her lock should be the first lock on the lockbox once the isolation keys are in the lockbox, and the last lock off of the lockbox when work has been completed. This will insure that the authorized person will be able to insure proper start-up/reenergization of equipment.
- A tag with the name of the person and the date of the lockout will be affixed to the lockbox.
- Each person applying a lock to the lockbox must sign and date the lockbox tag.
- Personnel entering the site to perform work on the isolated equipment must apply their lock to the box and sign and date the lockbox tag.
- As individuals complete their assigned tasks, they may remove their locks from the lockbox.

- When work is complete and equipment is ready to be returned to service, the authorized individual removes his or her lock from the box so that the restoration to service process may be performed.

CAR SEALS

A car seal—also referred to as a security seal—helps prevent someone from inadvertently moving a tagged valve or switch (they are so called because they were first used to seal railcars after they were loaded). However, because the car seal has very little physical strength, it is very easy to break if someone decides that it is in the way. The traditional form of car seal has been a wire loop with a tag attached to it—rather like a stronger version of a luggage tag. Modern car seals often use plastic ties.

Car seals do not provide sufficient security when hazardous chemicals are being used. They are more commonly used in operations such as blending, where an error can cause product quality problems, but not a safety concern.

PADLOCKS

Keyed padlocks should be used for locking out equipment and electrical devices. Each padlock should be keyed differently. Supervisors should retain spare keys for each padlock assigned to their work area.

Padlocks should be color-coded to identify the group which owns them. The following color code is an example:

- Yellow: Operations
- Red: Electricians
- Blue: Maintenance
- Green: Instrument Technicians
- White: Facilities Engineering

Depending on the facility (size and number of personnel), padlocks may be individually assigned or placed on a lock board for common use. A log should be maintained; it identifies who is using each padlock and where the padlock is being used.

Padlocks used for lockout and tagout should not be used for other purposes.

TAGS

Tags should be used to identify locations where equipment has been altered for lockout, including valves, flanges, skillets, spectacle blinds, switches, and blocking devices. The tag should identify the person who applied it, the reason the tag was applied, and the date the tag was applied.

Tags are almost always used as a supplement to the other methods. For example, a lock on a valve handle will have a tag on it providing information such as who has authority to remove the lock and what the work order number for this job is.

Tags may be color-coded in the same manner as locks. Tags should be markable, weather resistant, and contain an eyelet so they can be fastened to equipment with a tie-wrap or wire. Tags should be multilingual as needed to communicate information and potential hazards to the local workforce. They can also be multipart so that sections can be torn off and retained in a control room or other central location.

Tags should be substantial enough to prevent inadvertent or accidental removal.

REMOVING LOCKS AND TAGS

After each phase of the work is complete, the locks for that team may be removed. The work area should be inspected to ensure that nonessential items have been removed and that machine or equipment components are operationally intact. The work area should be checked to ensure that all employees have been safely positioned or removed from the area. The authorized employee will remove the last lock and release the "Do Not Start Tag" and notify the individuals responsible for the equipment that the repairs are complete and ready for service. After lockout or tagout devices have been removed and before a machine or equipment is started, affected employees should be notified that the lockout or tagout devices(s) have been removed. Contractors will not normally be authorized to return equipment to service. However, the team leader may authorize contractors to return field equipment to service when appropriate.

Each lockout or tagout device should be removed from each energy-isolating device by the employee who applied the device. When the authorized employee who applied the lockout or tagout device is not available to remove it, that device may be removed under the direction of team leaders, provided that specific procedures and training for such removal have been developed, documented, and incorporated into the company's energy control program.

All locations must have procedures for the removal of an employee's lock, or they may adapt procedures presented in this manual. It must be demonstrated that the specific procedure provides equivalent safety to the removal of the device by the authorized employee who applied it. The specific procedure should include at least the following elements:

1. Determine conclusively the job has been completed and no personnel remain in the affected area.
2. The team leader in charge will make all reasonable efforts to ensure that the employee is notified that his lock has been removed before the employee resumes work at the facility.
3. The team leaders, or the employee's relief, are authorized to use the above procedure and then remove the lock/tag.

The individual restoring energy to the equipment must:

1. Inspect the work to ensure that nonessential items have been removed.
2. Ensure that the equipment components are operationally intact.
3. Check the work area to ensure all employees equipment and tools are safely positioned or removed from the equipment.

Closing out the permit does not necessarily mean that the equipment is ready to start up. In particular, a tightness pressure test must be performed. A housekeeping check should also be carried out, with particular focus on the following:

- All trash has been removed
- All unused materials have been removed
- All scaffolding has been dismantled
- The site has been washed down
- Unused parts have been returned to the store
- The site is in a clean, tidy, and safe condition.

ELECTRICAL ISOLATION

Equipment must be isolated from all electrical energy sources by opening and locking all main power supplies. If the main power supply cannot be locked out, a qualified electrician must physically disconnect the equipment from the power source. Lockouts of electrical equipment are to be made at the main power supply—the use of local switches may leave other portions of the equipment energized. Once the electrical lockout is complete, an attempt should be made to start the equipment locally to ensure it is properly isolated before the maintenance work starts (and then all switches should be returned to their "off" position and tagged "Do Not Operate").

ADMINISTRATIVE CONTROLS

The fourth kind of energy control procedure, and the one that provides the least protection, is the use of procedures and other administrative measures. This approach consists of ensuring that a source of high energy is isolated using normal operating equipment such as valves, and then simply putting a tag on that equipment telling other personnel not to move the valve. A master plan is required, particularly when a complex set of lockouts and tags is required. A chart based on a piping and instrument diagrams can be prepared. It will show where all the locks, tags, and blinds are located. There must be a clear administrative procedure to determine which items need to be isolated and who has the authority to add and remove locks and tags.

When large numbers of people are in the area of the work that is being done, barrier tape and/or physical barriers should be put around the controlled area. Yellow tape warns an individual that he or she needs permission to enter an area or needs to get the attention of an individual inside the area to determine if entry is allowed. Red tape warns that a person may not enter an area because of potentially hazardous conditions that exist inside the zone. Violation of the space inside the red construction barrier tape is not acceptable and may lead to serious disciplinary consequences.

WORK PERMITS

Work permits are crucial to the safe operation and maintenance of process facilities. (They are also discussed in the section to do with job hazards analysis (JHA) forms in Chapter 2.) They can be divided into three categories: general, hot work, and confined-space entry. Permits are signed by both the operations and maintenance personnel involved in the work, and by their supervisors. The permit will have the following features:

- A clear and precise description of the work, including its location, the equipment to be worked on, the tools and equipment to be used, and the work methods to be employed. The description often requires other documents to be attached to the permit, such as JHAs, method statements, isolation lists, and drawings or sketches.
- A list of the preparations that must be made, including mechanical and electrical isolation, clearance of process materials by draining, venting, flushing, purging or ventilation, gas, and/or dust testing to confirm that the equipment is free of any flammable, toxic, or asphyxiating gases.
- Description of the hazards remaining. These may include residual process materials, pressure, temperature, and physical hazards arising from the location or work to be carried out.
- Additional precautions to be taken during the work such as the use of personal protective equipment (PPE), further gas testing, and additional monitoring.
- Precautions to be taken at shift handover.

GENERAL WORK PERMITS

General work permits are issued for all work that does not involve the use of open flames, hot surfaces, or entry into confined spaces. They cover tasks such as the following:

- Work in areas where electrical cables, telephone cables, or pipelines run above or below ground

- When scaffolding or cranes are to be used in the vicinity of in-service equipment
- Excavation work, particularly if shoring is involved (some excavation may count as confined-space work)
- The use of radiation such as X-rays
- Whenever flammable or toxic gases, vapors, oils, or chemicals are present

Issuance of permits

Before the permit is issued, all hazards associated with the work should have been identified, and controls put in place. The person who issues the permit is different from the permit holder. A person cannot issue a permit for themselves because one of the objectives of the system is to make sure that a second, qualified person critically reviews the hazards and the proposed controls. If a contractor is the permit holder, then the permit should be issued by a qualified person from the host company.

At least two copies of the permit are needed, one to be displayed at the work site, and the other to be held at the issuing point. The copy at the work site should be available for reference at any time by any member of the work team.

The issuance of a general work permit will normally require that the following steps be carried out:

- The person in charge of the work reviews the hazards identified in the pre-job plan and states what safety precautions must be followed during the course of the work. These can include PPE, gas retesting, continuous gas monitoring, spark containment, and the use of fire extinguishers. These conditions are noted on the work permit.
- Management approves the permit for a specified time period.
- Typically, a work permit is valid for one work crew. At shift change, or at the start of work the next day, the permit must be reissued.

Changes in conditions

The permit should specify the action to be taken in the event of:

- The specified equipment or tools to be used not being available.
- Changes to the type of work, e.g., the need for hot work when such work had not been in the original plan.
- Changes in process conditions such as an unexpected release of gas from a nearby flange.
- A gas alarm or emergency in the area.
- Changes in the weather.

When events such as these take place, the normal process is to stop the work and to refer the permit back to the permit issuer. He or she will reassess the work and conditions and either reissue the permit or issue a new or amended permit.

Multiple work permits

If two or more jobs are being carried out on the same piece of equipment or in the same area, the chance for confusion as to which permit applies to which controls arises. Failure to control multiple permits was a major factor in the Piper Alpha incident—two permits were open on one compressor. When the first job was finished, its permit was closed and the compressor was started, even though the machine had a missing blind flange associated with the second job.

A display board at the permit issuing point is an effective means of maintaining an overview of all the work under permit control and of the potential interaction between jobs. Such a board also facilitates communication at shift handover.

HOT WORK PERMITS

Hot work involves the use of flame-producing equipment, such as welding or cutting torches, or the use of equipment that can create sparks, such as can occur when metal is being cut or hammered. Hot work is potentially dangerous for the following reasons:

- It provides a source of ignition that could ignite a vapor release from another location.
- The person doing the hot work may cut through the wrong line or burn a hole in the wrong piece of equipment. This could lead to the release of hazardous chemicals, or cause a fire or explosion.
- The person doing the work could be burned by the equipment that they are using.
- In confined spaces, the hot work itself can create a harmful atmosphere, leading to the possibility of a worker being overcome by fumes.

A hot work permit is needed whenever the work involves open flames, arc welding, electrically sparking equipment, or other ignition sources within a predefined distance, such as 15 meters, of facilities handling flammable or combustible materials.

A hot work permit includes all the elements of a general work permit. In addition, the following checks should be carried out before the permit is issued:

- Inspection of the site
- Vapor testing
- The availability of firefighting equipment

The following questions should be considered as the hot work permit is being prepared:

- Can the work be done in a less hazardous area?
- Can the job be done by cold work?
- Has the site been inspected by a responsible individual?

- Have pipelines or equipment that may release flammable or combustible materials been blinded off or disconnected?
- Are pipelines or equipment to be worked on vapor-free or vented?
- Have process liquids been drained from all low points?
- Are bleeders open and unplugged?
- Have openings to sewers and underground drains within 15 meters of the work been sealed?
- Are operating activities (e.g., venting, sampling) likely to release flammable vapors or liquid to the atmosphere within 15 meters of the hot work area?
- Are flammable vapor tests necessary?
- Are fire hoses and portable extinguishers available?
- Are there any chemicals in the area that could be a hazard to firefighters?
- Is it necessary to redirect venting from relief systems away from the hot work area?
- Are workers in adjacent areas and affected plants aware that the work is going on?
- Will working conditions remain safe for the duration of the job?
- Do the fire watch personnel know what to look for and what to do if hazardous conditions arise?
- Do they know how to use emergency equipment properly?
- Are radio communications between the fire watch and the control room/supervisor needed?
- Are combustible materials such as wood or rags present?
- Are fire screens and blankets required to contain sparks and slag?
- Are high-velocity, high-volume, electrically classified fans required to direct potentially flammable vapors away from the area?
- What is the chance that wind-borne hot particles could drift outside the hot work area?

CONFINED-SPACE ENTRY

A confined space is a space which is large enough for a worker to enter but has limited openings for entry and exit and is not intended for continuous employee occupancy. Entry is considered to have occurred as soon as any part of the entrant's body breaks the plane of an opening into the space. Therefore, it is not permissible, e.g., to take a quick breath and to put one's head into a vessel for a quick look without having an entry permit. Wherever possible, work should be organized such that it can be carried out without anyone needing to enter the confined space. If someone does need to enter the confined space, the most rigorous controls and procedures must be followed.

Confined spaces include, but are not limited to, storage tanks, towers, drums, boilers, furnaces, sewers, ventilation and exhaust ducts, underground utility vaults, manholes, pipelines, excavations, and pits. A *confined* space is not the same as an *enclosed* space. Therefore, most pipeline trenches are also considered to be confined spaces, even though they are open to the atmosphere. A person working in a trench could be trapped by falling materials or overcome by fumes from a leak. He or she cannot easily escape since they will have to climb out of the trench, probably using a temporary ladder. Entry onto the roof of an external floating roof tank when the roof is more than 1 meter below the top of the shell also constitutes entry into a confined space.

A confined space should be big enough for a person to enter bodily. A small box such as a metering station may contain hazards such as venomous animals. However, since a person cannot enter with his or her whole body, they would not normally be considered as confined space (although some legal interpretations may differ).

Sometimes it is not always clear when a space should be treated as "confined." On one marine vessel, e.g., a worker entered a room containing equipment and was fatally overcome by fumes. It is likely that he thought of the room as being part of the normal work space and so no special precautions were needed.

Confined spaces are classified as either hazardous or nonhazardous. A hazardous space is one that is known to contain a hazardous gas. The gas could be inert (such as nitrogen), toxic (such as hydrogen sulfide), or flammable (such as methane). A nonhazardous space is one that has been purged with air such that a person entering the space does not need breathing apparatus. However, before a person enters a nonhazardous space, the atmosphere in that space must be tested for oxygen and must be retested on a frequent or continuous basis. Similarly tests should be conducted for the presence of hazardous gases. The test instrument should be at the same location as the person performing the work.

The following general guidance should be considered when planning confined-space work in a vessel:

- Prior to approving personnel entry, the vessel must be positively isolated by blinding or disconnecting all connections to the vessel, except the purge gas connection, to prevent accidental contamination of its inert atmosphere during entry by personnel. Where blinding or disconnecting piping is not feasible, e.g., welded piping systems, a double block, and bleed system may have to be considered.
- Maintain a list of authorized entrants, designate an entry supervisor, and provide a means to prevent unauthorized entry.
- Energized equipment must be brought to a safe energy state, locked/tagged out, and radioactive sources must be shielded and locked/tagged out, or removed.
- Prior to entering an inerted confined space, conduct tests to determine oxygen content, and % LEL (Lower Explosive Limit) of the atmosphere at conditions which are as close as reasonably possible to the actual entry conditions and with all service equipment operating.

- The oxygen content of the atmosphere within the vessel must be monitored continuously with equipment capable of recording low oxygen levels.
- The temperatures within the vessel must be monitored continuously. If any temperature rises 10°C (above normal day/night variations), personnel must leave the vessel until it is assured that their safety is not jeopardized due to an exothermic reaction or other such potentially harmful situations.
- Standby personnel and rescue equipment must be available at the confined-space entry point. The rescue equipment must be assembled and ready for use. Rescue personnel must be trained in the proper use of this equipment.

TYPES OF SPACE

Confined-space entry can be divided into two broad areas: nonhazardous spaces which have been ventilated and hazardous spaces that are known to contain hazardous materials.

Nonhazardous space

Before a person can enter a nonhazardous confined space, the following conditions must be met:

- It must be shown that the work cannot be accomplished from the outside.
- The oxygen content must be in the range 19.5%–23.5%.
- The flammability level must be below 10% LEL.
- There are no toxic gases in the confined space.
- The space does not contain grain, sand, or other solid material that could flow and engulf a worker.
- The temperature in the confined space should be normal. If the space was purged with steam prior to entry, it should be cooled down.
- Noise should be controlled. Confined spaces can be very noisy because of the echoes that are generated.
- The equipment being worked on is properly isolated.

Hazardous space

A hazardous confined space is defined as containing, or having the potential to contain, "a recognized serious safety or health hazard," in other words the space is known to contain hazardous materials and therefore the workers entering that space must wear protective clothing and breathing apparatus. Such as space will meet one of more of the following conditions.

- An oxygen concentration less than 19.5% or greater than 23.5% and/or maintained inert by gas purging.
- Lower explosive limit (LEL) greater than 10%. If the confined-space atmosphere exceeds 10% LEL, then additional ventilation is needed, or the space must be inerted prior to entry. The need for continuous mechanical

(forced) ventilation should be determined on a case-by-case basis and noted on the permit.
- An atmospheric concentration above the permissible exposure level (PEL) of a toxic substance or an atmospheric concentration of any substance that is immediately dangerous to life or health (IDLH).
- An airborne combustible dust at a concentration that exceeds its lower flammable limit (LFL).
- A confined space that contains a material that could physically engulf the entrant.
- A confined space that has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or floor which slopes downward and tapers to a smaller cross section.

Extraordinary precautions are necessary for entry into a hazardous confined space due to the inherent danger. Special precautions include training of all participants, assigning an outside attendant, maintaining a list of authorized entrants, assigning an entry supervisor, the provision of breathing air, and the use of retrieval systems.

One special type of hazardous space is one where the atmosphere in a vessel must be kept inert because the vessel contains special chemicals or catalysts that would be damaged or could catch fire if exposed to oxygen. Special written job procedures, detailed planning, and training prior to entry must be developed and followed to perform this work safely and efficiently.

THE ENTRY PERMIT

A confined-space entry permit, which should be posted at each entry point to the confined space, should meet all the general permit requirements and should also contain the additional following sections:

- A description of the confined space.
- Reason for entry.
- Date and duration of the entry permit.
- The name of the supervisor in charge.
- The names of those authorized to enter the confined space.
- The name of the attendants (buddies) at the entry to the confined space.
- Suitably trained rescue personnel and equipment must be readily available to respond to the work site. Procedures for summoning the rescue services must be understood by all personnel who will enter the confined space.
- Communication procedures between entrants and attendants.
- Hazards of the space, including possible changes in the atmosphere that may occur as a result of the work itself. For example, if a coating is being applied, then the fumes could affect the air quality.
- PPE or ventilation requirements.
- Isolation methods.

- Entry conditions (such as the level of oxygen in the air in the space).
- Energized equipment must be brought to a safe energy state, locked/tagged out, and radioactive sources must be shielded and locked/tagged out or removed.
- Information about emergency services.
- Equipment allowed for work in the confined space.
- Additional permits needed for activities such as hot work.

At all times, the confined-space work entrances should be posted with a sign reading "DANGER—PERMIT-REQUIRED CONFINED SPACE, DO NOT ENTER."

If the conditions in a confined space change at any time, the entry permit must be reissued.

PERSONNEL

Depending on the type of work that is to be done, the following personnel are involved in confined-space work:

- The entrant
- The supervisor
- The manway attendant (buddy)
- The gas tester
- The rescue team

Entrant

The entrant is the person entering the confined space in order to carry out the necessary work. He or she should:

- Know the hazards of the confined space where he or she is to work.
- Be familiar with the tasks to be carried out in the confined space.
- Wear all designated protective equipment.
- Know how to use emergency equipment and be familiar with the emergency plan.
- Know how to communicate with the manway attendant.

Supervisor

The entry supervisor should:

- Know the hazards of the confined space.
- Prepare and sign entry permits.
- Verify that all tests have been carried out.
- Ensure that outside contractors comply with the company's policies.
- Terminate entry for any reason, but particularly if a hazardous situation develops.
- Cancel the permit once the work is completed.
- Verify that appropriate rescue and emergency services are available.

Manway attendant

Every confined-space job should have at least one person on duty outside the space. This person, sometimes referred to as the manhole watch, must stand far enough away from the work so that he or she is not overcome by any fumes that may be generated during the course of the work.

The attendant's primary role is to monitor the condition of the persons in the confined space and to initiate action if there seems to be a problem. Usually this is done by establishing radio communication between the attendant and the entrant(s). The attendant also ensures that no unauthorized person enters the confined space, and summons rescue services, if needed.

The attendant has the following duties:

- Maintain an accurate count of the number of people in the vessel.
- Maintain constant two-way communication with all of the occupants.
- Provide standby assistance to occupants entering the confined space.
- Wear appropriate protective equipment at all times.
- Instruct occupants to leave the confined space if any conditions change such that the entry permit is invalidated.
- Monitor for changes that could lead to the occupants to be exposed to hazardous conditions.
- Remain at the entry point at all times.

An attendant can monitor more than one space if they are close together and if he or she can carry out his duties at each location.

The attendant should not enter the confined space unless authorized and trained to do so. If there is an emergency, the attendant may attempt rescue without entering the confined space. Otherwise rescue should be handled by a properly trained team.

Gas tester

The person testing the atmosphere inside the confined space must be properly trained. He or she must know the use, limitations, calibration, and inspection of testing equipment and must also understand how conditions inside the space could affect the reliability and calibration of the testing equipment.

Rescue team

A properly trained rescue team should be available to rescue workers from the confined space.

PREPARATION

Generally there are five steps to preparing a confined space for entry, which is as follows:

1. JHA
2. Isolate the equipment

3. Drain liquids, purge, and ventilate
4. Test for oxygen content and toxic gases

Job hazards analysis

The general procedure for completing a JHA is discussed in Chapter 2. A confined-space entry JHA should include the following steps:

- The area surrounding the confined space should be checked for hazards such as drifting vapors from other tanks, drains, power, and equipment.
- All potential sources of engine exhaust and fuel vapors have been identified and removed or effectively controlled.
- A rescue plan that identifies escape routes and emergency egress methods should be prepared. The plan should be reviewed by all affected personnel.

The JHA will result in a written procedure that describes how the work is to be done. The procedure should describe the equipment and support that will be needed by the persons doing the work. This will cover items such as safety harnesses, ventilation, communication with support systems, and breathing gear. Also included in the plan is a description of the immediate support system—sometimes called the buddy system where someone remains outside the confined space and is in constant communication with those inside. The procedure should describe how the person doing the work communicates with his buddy, how he or she can be pulled out of the confined space in the event of an accident, and how additional help can be obtained.

If hot work is to be carried out in the confined space, then all the normal hot work permit requirements must be met. Additional issues to consider include the following:

- Burning, welding, and torch-cutting consume oxygen and produce metal fumes. When this type of work is being done, it is particularly important to conduct frequent gas tests.
- Airflow must be away from the worker and must be sufficient to remove fumes and smoke.
- Gas cylinders should be left outside in an upright position.
- Welding hoses and cables should be checked thoroughly for leaks and cracks before the work starts.
- Removal of unused hoses from the confined space.
- Barriers and warning signs should be placed at all openings.

Isolate the equipment

The equipment being worked on should be isolated using the procedures and systems already discussed. In particular, the confined space must be positively isolated by blinding or disconnecting lines. Isolation by closing block valves is not sufficient.

Measures must be taken to prevent entry until the confined space has been tested and approved for entry, including appropriate use of barriers, warning signs, and training.

Drain liquids, purge, and ventilate

The vessel or work area must be drained as completely as possible. Often liquid will remain trapped on vessel internals, such as pieces of packing or tray parts. In such cases, water can be added to the vessel such that the process material is either dissolved or floated off. Alternatively, all large openings such as manholes can be opened, and the vessel can be steamed out.

The internals of storage tanks may contain partially corroded sections that contain residual process liquids, even after the vessel has been purged. If workers detect such pockets, additional purging should be carried out.

Once liquids have been removed, the equipment is purged and ventilated. Purging is generally done with an inert gas such as nitrogen or steam. It can also be done with water flooding. The equipment is then ventilated with air.

Steam is frequently used because it is often readily available and is not expensive. Also, where the presence of iron sulfide could be a fire risk, the condensed steam helps keep those deposits moist, thus reducing the chance of them spontaneously catching fire. Generally steam enters at an opening near the bottom of the vessel and is discharged from an opening at the top. All other openings should be kept closed. To effectively displace the vapor that is in a vessel, the steam must be supplied at a sufficiently high rate so that it does actually sweep the vapor ahead of it, and does not just condense on the cool walls of the vessel. This means that the temperature of the vessel will become quite high—say 75°C or more.

If a vessel or tank is not vacuum rated, care must be taken that the item is not closed up with steam still in the vapor space. Otherwise, once the steam condenses, low pressure could cause the equipment item to be pulled in.

Ventilation air can either be blown in at the base of the tank or vessel, or pulled through the vessel by an eductor at the top. The flow should be high enough to create several total air changes each hour. Air ventilation not only removes contaminants, but it also helps to cool the space. However, air does have the following limitations as a purge gas when compared with steam:

1. It does not provide heat to assist in hydrocarbon freeing a system.
2. It is more difficult to determine plugged vents and drains.
3. It is also more difficult to find leaks during pressure tests for start-ups.
4. It does not keep potential pyrophoric iron sulfide wet.
5. Some of the commonly used gas detectors will not detect hydrocarbons in a nitrogenous atmosphere.
6. Its delivered purity should be continuously monitored to insure hazardous contaminants such as oxygen are not introduced.

The flow of ventilation air must be maintained for the duration of the work. If the flow stops for any reason, the workers must leave the confined space immediately.

The exhaust air must not be discharged close to buildings or the intakes of heating, ventilation, and air conditioning (HVAC) systems. If two or more vessels are being purged, their vent discharges should not be connected to the same exhaust system if the mixed stream could cause a fire or chemical reaction.

In some locations, it may be necessary to place a carbon filter bed on the air discharge for environmental reasons. In such situations, the filters need to be replaced or cleaned regularly to prevent significant reductions in airflow.

TEST

Before a person can enter the confined space, the internal atmosphere should be tested for oxygen content and for the presence of toxic gases. The test should be carried out in various parts of the equipment item, particularly those areas where unpurged gases may have accumulated. The test should be repeated at regular intervals during the course of the work.

TIE-INS

When fabrication work is being carried out on an existing facility, it is often convenient to prepare a list of all the tie-in points that will be needed, then to shut the process down so that all those tie-ins can be put in place at one time. Then, as new pieces of equipment and piping arrive on site, they can be installed without interrupting ongoing operations. Figure 3.3 shows some details as to how such a tie-in is made.

An existing process line is shown at the left of Figure 4.3. During a shutdown of the tee, the two block valves and the two bleed valves are added, as shown. Assuming that the tee is not needed right away, all of the valves are left in the

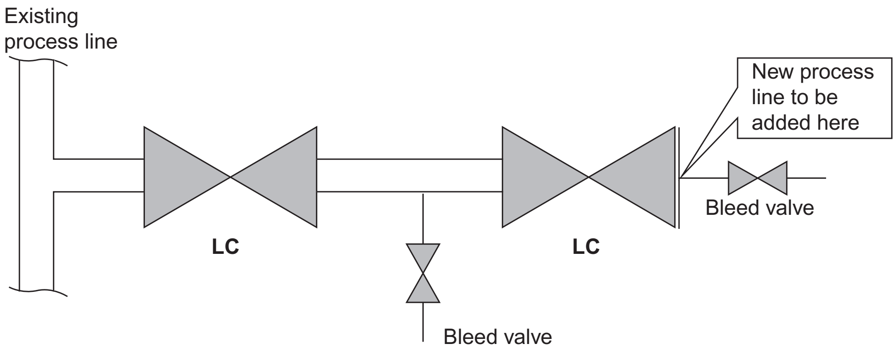

FIGURE 3.3

Tie-in preparation.

closed position (the block valves should be locked). When the new equipment is ready to be installed, a pressure gauge is added to the outer bleed valve, which is then opened. If the pressure gauge shows no increase in pressure than the valves are holding, the outer blind plate can be removed and the new line installed. If the pressure gauge does show some pressure, then it will be necessary to determine which of the large valves is leaking, and to repair it. If the inner valve is leaking, then a second system shutdown may be required.

HOT TAPPING

Hot tapping is a process whereby a connection can be welded to a pipe or tank. In the case of a pipe, the flowing fluid will remove the heat. For tanks the heat is removed by the movement of the heated fluid (with tanks containing liquid, the work should always be done at least 1 meter below the liquid level).

Hot tapping is inherently hazardous and should only be done when:

- Continuity of service is essential.
- Shutdown of the system in impractical.
- Documented procedures are followed.
- Equipment is used which will provide proven effective protection for employees.

PLUGGED LINES

Process lines, piping, and valves frequently become plugged. Various techniques for avoiding the formation of pluggage and for removing pluggages safely are discussed in this section.

If line pluggage is a recurring problem, it is best to try and identify ways in which the problem can be prevented from occurring. If that solution is not possible, then valves, drains, tees, and connections should be designed so that it is possible to remove the pluggage safely and with minimum time and expense.

PREVENTION OF PLUGGAGE

It is obviously much better to prevent pluggage from occurring—all of the techniques for unplugging lines pose safety risks, and the time for which the line is out of service will normally lead to production losses. The following techniques can help prevent pluggage:

- Install filters and strainers, and ensure that they are replaced or cleaned on a regular basis.

- Install low point drains to remove water, thereby reducing the chance of hydrate formation. The water should be drained on a regular basis. Also, use antifreeze agents, such as methanol or ethylene glycol, to prevent hydrate formation.
- Drain and flush pipe branches that have no normal flow with an inert, noncorrosive liquid on a regular basis.
- Maintain adequate flow in lines that contain materials that will solidify at low temperatures. These lines should also be insulated, and heat traced as appropriate.
- Maintain adequate flow/minimum velocity in lines that contain materials that could settle out.
- Provide and maintain bleed gas or flushing oil flows to instrument taps that are prone to plugging.
- Where possible, any hazardous or reactive material that may be in the plugged equipment should be removed before the pressure is increased.
- Vent all gas pockets since they will contain considerable energy when under pressure.
- Do not leave open drain valves or open-ended piping unattended at any time during unplugging operations.
- Provide a place to bleed off pressure upstream of the obstruction, particularly if the obstruction is not cleared.
- Provide containment for the system contents once the line becomes unplugged.
- Identify locations to which the plug could travel and take precautions to protect personnel and equipment in those areas.
- Flush idle lines to remove materials that could clog piping.
- Install adequately sized filters, strainers, and knockout drums. Change out, flush, or drain these devices as needed.
- Water in a hydrocarbon stream can cause plugging by increasing corrosion rates, forming hydrates, or freezing. Install and use low point drains. Draw water regularly from vessels and tanks. Automatic draws may be appropriate for some problem areas.
- Water washes can be used to remove salts that will cause plugging.
- Pipe branches that frequently experience no flow are highly susceptible to plugging. Employ a self-draining design to avoid the collection of water and/or sediment. When practical, locate valves in horizontal sections of piping to avoid the accumulation of water and/or sediment above the valves. The use of "ram type" drain valves have been successful in keeping drain valves clear of ice and debris.
- Maintain adequate flow in (or insulation and heat tracing around) lines that contain materials that will solidify at low temperatures.
- Maintain adequate flow/minimum velocity in lines that contain materials that could settle out, e.g., catalyst in decanted oil.
- Provide and maintain bleed gas or flushing oil flows to instrument taps that are prone to plugging.

UNPLUGGING A LINE

Pluggages can be removed in the following ways:

- Water wash to remove salts that are causing the problem.
- Disassemble and replace the affected piping.
- Hydroblast.
- Applied heat to melt the obstruction. The heat can come from electric coils, steam tracing, or live steam.
- Chemicals to dissolve the obstruction. For example, methanol can be used to melt the ice in the hydrates that block subsea lines.
- Mechanical.
- Differential pressure.

When unplugging underground lines, a line rupture may give the appearance that the plug is dislodged by a sudden drop in pressure. The clearance should be verified by flowing gas or liquid through the line.

The following general precautions should be observed:

- All piping and hoses should be properly anchored.
- Always wear appropriate eye protection when applying pressure to a piece of equipment.
- Wear appropriate gloves, hoods, and clothing to prevent exposure to any thermal or chemical hazards.
- Air-supplied respirators are required when using an inert gas in a confined space or when unplugging equipment that could contain a toxic material, such as hydrogen sulfide.
- Identify locations to which the plug could travel and take precautions to protect personnel and equipment in those areas.
- Provide a place to bleed off pressure upstream of the obstruction. Release of pressure should be verified before disconnecting the piping, hose, etc.
- Reduce the likelihood of utility system contamination by providing a check valve whenever a utility stream is used to unplug process equipment.
- Temporary connections should be disconnected when the unplugging work is complete, even if they may be needed again at a future date.
- Precautions should be exercised when:
  - Rapidly pressurizing/depressurizing to bump free the obstruction.
  - Applying pressure to the opposite side of the obstruction.
  - Striking the plugged equipment to jolt the obstruction loose.
  - Any piping or hoses used with compressed gas should be properly anchored.
- When unplugging underground lines, a line rupture may give the appearance that the plug is dislodged by a sudden drop in pressure. The opening should be verified by flow in and out of the line.

MECHANICAL

If a line does plug, it may be possible to remove the obstruction by striking the line or by using a drill or augur. Each of these has associated risks: striking the line could cause mechanical damage, and the use of a drill means that the equipment has to be opened up.

DIFFERENTIAL PRESSURE

Applying pressurized fluid to one side of an obstruction can be an effective method for forcing it to move. However, this approach can cause serious injuries if it goes awry; therefore, the following points should be considered before applying differential pressure:

- The general procedures for pressure testing equipment and piping must be followed. Liquid should be used wherever possible. In all cases a Job Hazards Analysis (JHA) should be performed before pressure is applied. The analysis should ensure that the fluid used will not cause corrosion. Always increase pressures slowly.
- When using compressed gas cylinders make sure the regulator has the proper threads and pressure rating.
- Where possible, displace any hazardous or reactive material that may be in the plugged equipment before applying pressure.
- The fluid's temperature must be above the point where brittle fracture can occur.
- Consider possible effects of the fluid's temperature on adjacent systems or equipment. Heat should not be applied to one side of a system if the other side is blocked in.
- After the general location of the obstruction is determined, identify which equipment should be pressurized including equipment which can become pressurized when the plug clears. Take precautions to prevent excessive pressure build-up in adjacent or downstream equipment such as installing blinds or closing valves and opening vents.
- Specify the maximum pressure that will be applied to the equipment. Normally, the pressure should be kept below the system's design pressure. If a higher pressure is required, determine the maximum allowable working pressure (MAWP) for each piece of equipment being pressurized.
- Procedures for strength testing must be followed if the MAWP for a piece of equipment will be exceeded or if any relief valves are to be disabled. Never exceed the recommended strength test pressure of any equipment.
- Identify internal components that may only be designed to withstand operating differential pressures, e.g., bellows, differential pressure cells, and exchanger

tube sheets. Avoid putting excessive pressure on only one side of these components.
- Check that hoses, regulators, and associated apparatus have an adequate pressure rating. When using compressed gas cylinders, make sure the regulator has the proper threads and pressure rating. The maximum allowable pressure is usually stamped on the regulator's collar.
- Temporary operating and maintenance procedures for the work should be developed.
- Raise pressures slowly and consider the possibility that the pressure gauge may itself become plugged by the material (e.g., wax) as pressure is applied.
- Consider installing a relief valve downstream of the pressure regulator to protect the equipment in case the regulator fails. This is particularly appropriate when using high-pressure gas for unplugging low-pressure systems.
- Do not leave open drain valves or open-ended piping unattended at any time during unplugging operations.
- Plans should be made to contain the system contents once it becomes unplugged.
- Personnel assisting in the unplugging operation should position themselves in a safe location.

Fluid selection

Whenever practical, a nonhazardous liquid (such as water) should be the unplugging fluid. A compressed gas will release much more energy when the plug is freed (or if the equipment ruptures). In all cases, the liquid or gas used to apply pressure should be compatible and not reactive with any equipment or material that it could contact.

If a liquid is used, the following precautions should be taken:

- All gas pockets should be vented from the equipment since a liquid–gas mixture will also contain considerable potential energy.
- The equipment, supports, and foundations must be able to withstand the additional weight from the liquid.
- Use a chloride-free fluid to unplug equipment fabricated of austenitic stainless steel.
- Consider the effects of any possible changes to the fluid's temperature during the unplugging operation.
- Bleed off any excess pressure resulting from thermal expansion of the fluid. A small temperature rise can overpressure liquid-filled equipment.
- To prevent a rapid pressure surge caused by a flashing liquid, avoid using a liquid that could be heated above its atmospheric boiling point during the unplugging procedure.

Steam

If steam is used, the following guidance should be considered:

- Use dry (condensate-free) steam when blowing out taps into high-temperature equipment. Flashing condensate could cause a rapid rise in the equipment's pressure.
- When using a steam lance to unplug piping, deck drains, or sewers, locate a valve between the lance and the steam hose for easy shutoff.
- Steam lances should be secured to equipment if left unattended. A hose should not be used in place of a steam lance.
- To avoid a buildup of static charge, the steam lance should be in contact with equipment, secured with conductive material, or otherwise grounded.
- Care should be taken to remove traces of condensed steam before returning equipment to hot-oil service. During cold weather, the condensate should be removed before it freezes.
- Condensing steam could pull a vacuum on the equipment. The vacuum could collapse a vessel or pull unwanted air into the system.

Compressed gas

If compressed gas from cylinders is used to clear the obstruction, then all the normal procedures to do with the safety of these cylinders should be followed. In addition, the following special precautions should be considered:

- Ensure that oxygen-deficient breathing areas are not created at points where the plugged equipment could blow out. Consideration should be given to supplying respirators in such areas.
- Air should only be used in systems that are free of combustibles to prevent the formation of an explosive mixture.
- Air must be purged from the equipment before returning it to hydrocarbon service.
- Do not use pure oxygen or a flammable gas.

CHAPTER

Occupational safety

4

CHAPTER OUTLINE

INTRODUCTION

Occupational Safety — sometimes referred to as personal or hard hat safety — is concerned with events that result from unsafe acts or conditions, and that generally affect only one person, or a small group. It covers topics such as vessel entry, vehicle movement, protective clothing and tripping hazards. Process safety,

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on the other hand, focuses on process-oriented issues such as runaway chemical reactions, corrosion and the inadvertent mixing of hazardous chemicals. (Process Safety Management is discussed in depth in *Process Risk and Reliability Management.*)

MEASURING PERFORMANCE

In order to be measure safety performance a consistent set of terms and reporting standards is required. In the area of occupational safety, considerable standardization has already been achieved through the use of measures such as the number of first aid cases or recordable injuries. Although different organizations will apply these terms slightly differently from one another, there is sufficient consensus to allow for their use across broad swathes of industry. These data are referred to as lagging or trailing indicators.

The following indicators are used to track safety and environmental performance. They are often used as key performance indicators (KPIs) that are reported on a regular basis.

- Fatalities
- Days away from work
- Recordable injuries (as a function of exposure hours)
- Recordable illnesses
- Spills from primary containment (even if secondary containment was effective)
- Spills affecting the environment (failure of all containment barriers)
- Volume of oil spilled that is not recovered
- Greenhouse gas emission equivalents
- Total hydrocarbon emissions
- Total SO_x and NO_x emissions
- Total discharges to water
- Total hazardous waste

Companies in the United States pay particular attention to the Occupational Health and Safety Administration (OSHA) recordable rate that facilities report. An OSHA recordable injury is an occupational injury or illness that meets one of the following criteria:

- Death
- Loss of consciousness
- Days away from work
- Restricted work activity or job transfer
- Medical treatment beyond first aid

It is calculated for the previous 3 years and is defined as

$$\frac{\text{Number of Recordable Cases} \times 200,000}{\text{Total Hours Worked}}$$

The OSHA lost workday incident rate is similar:

$$\frac{\text{Number of Lost Workday Cases} \times 200,000}{\text{Total Hours Worked}}$$

A lost workday—equivalent to a lost time injury—is one where an individual misses more than 1 day of work due to an injury sustained while at work is another widely used criterion for measuring occupational safety.

SAFETY MANUAL

Companies generally prepare a safety manual that summarizes and indexes their various occupational safety policies, programs, and procedures. Table 4.1 provides a sample Table of Contents for such a manual. Background information, such as the design of the firewater system, will be provided in process safety documents. Many of the topics listed in Table 4.1 are discussed in other parts of this book.

Table 4.1 Representative Table of Contents for Safety Manual

1. Introduction
2. Safety Policy and Philosophy
    - 2.1. Regulatory Inspections/Litigation
    - 2.2. Safety Meetings
    - 2.3. Training/Recordkeeping
    - 2.4. Process Unit Entry/Exit Procedures
    - 2.5. Smoking Policy
    - 2.6. Personnel Working Alone
    - 2.7. Bulletin Boards
    - 2.8. Housekeeping
    - 2.9. Safety Signs and Color Coding
    - 2.10. Machinery Guarding
3. Employee Exposure and Medical Records
    - 3.1. Notification
    - 3.2. Record keeping
    - 3.3. Medical Examinations
    - 3.4. Access
4. Incident Reporting and Investigation
    - 4.1. General

(*Continued*)

Table 4.1 Representative Table of Contents for Safety Manual *(Continued)*

- 4.2. Near Miss Incident Reporting
- 4.3. Occupational Injuries and Illnesses

5. Hazardous Materials
   - 5.1. Chemical Inventory List
   - 5.2. Material Safety Data Sheets Management
   - 5.3. Labels
   - 5.4. Contractor Notification
   - 5.5. Recordkeeping
   - 5.6. Hazard Communication Program
   - 5.7. HAZWOPER
   - 5.8. Combustible and Flammable Liquid Storage and Handling
   - 5.9. On-Line Blending
   - 5.10. Asbestos
   - 5.11. Benzene
   - 5.12. Hydrogen Sulfide
   - 5.13. H_2S Detection Equipment
   - 5.14. Sulfur Dioxide
   - 5.15. Ammonia
   - 5.16. Hydrofluoric Acid
   - 5.17. Sulfuric Acid
   - 5.18. Caustic Soda (NaOH)
   - 5.19. Caustic Potash (KOH)
   - 5.20. Chlorine
   - 5.21. Hexavalent Chromium
   - 5.22. Mercury
   - 5.23. Pyrophoric Iron Sulfide
6. Environmental
   - 6.1. Solid Waste Handling
   - 6.2. Spill Prevention Plan
   - 6.3. Screwed Pipe
   - 6.4. Sewers and Drains
7. Electrical
   - 7.1. Area Classification
   - 7.2. Equipment Grounding
   - 7.3. Ground Fault Interrupters
   - 7.4. Electrical Power Generation, Distribution, and Transmission
   - 7.5. Overhead Lines
   - 7.6. Climbing Electrical Line Poles
   - 7.7. Working on Switchgear
   - 7.8. Stray Electric Currents
8. Authorization to Work
   - 8.1. Permits and Procedures

Table 4.1 Representative Table of Contents for Safety Manual *(Continued)*

8.2. Energy Isolation Procedures
8.3. Gas Testing Policy
8.4. Hot Work Permit
8.5. Welding
8.6. Engineering and Administrative Controls
8.7. Sign Requirements
8.8. Permit Requirements
8.9. Tank Roofs
8.10. Fire Watch
8.11. Atmospheric Testing
9. Lockout/Tagout
9.1. Locks and Tags
9.2. Lockboxes
9.3. Blinding and Equipment Isolation
9.4. Barricades
9.5. Restoring Service to Equipment
10. Confined Space Entry
10.1. General
10.2. Permit System
10.3. Contractors
10.4. Rescue and Emergency Services
10.5. Block Valve Pits
11. Alarm Systems
11.1. Critical Alarms
11.2. Shutdown Systems
12. Combustible Gas Detectors
12.1. Portable
12.2. Fixed
12.3. Calibration Schedule
13. Driving
13.1. Reporting Accidents
13.2. Heavy Vehicles
13.3. Light Vehicles
13.4. Vehicle Backing
13.5. All-Terrain Vehicles
13.6. Use of Mobile Phones/Texting
13.7. Forklift and Truck Operations
13.8. Vacuum Trucks
14. Compressed Gas Cylinders
14.1. Oxygen
14.2. Acetylene

(*Continued*)

Table 4.1 Representative Table of Contents for Safety Manual *(Continued)*

- 14.3. Transporting Cylinders
- 14.4. Storage

15. Tank/Vessel Cleaning
    - 15.1. General
    - 15.2. Tank Preparation
    - 15.3. Chemical Cleaning
    - 15.4. Loading/Unloading Flammable Liquids and Compressed Gas
16. Personal Protective Equipment
    - 16.1. Safety Glasses
    - 16.2. Goggles
    - 16.3. Face Shields
    - 16.4. Fire-Resistant Clothing
    - 16.5. Respiratory Protective Equipment
    - 16.6. Breathing Air Quality
    - 16.7. Hearing Protection
    - 16.8. Face Protection
    - 16.9. Facial Hair Policy
17. Fall Protection
    - 17.1. Ladders and Scaffolding
    - 17.2. Fall Protection System
    - 17.3. Fall Arrest System Equipment
    - 17.4. Fall Protection Anchor Points
18. Health
    - 18.1. Hearing Conservation
    - 18.2. Audiometric Testing
    - 18.3. Contact Lenses
    - 18.4. Heat/Cold Stress
    - 18.5. Bloodborne Pathogens Exposure Control Plan
    - 18.6. Vaccination and Follow-Up Procedures
    - 18.7. Carcinogenic Materials
    - 18.8. Radiation Safety
    - 18.9. Refractory Ceramic Fiber (Asbestos Substitute Fibers)
19. Emergency Management
    - 19.1. Emergency Notification
    - 19.2. Securing Buildings for a Toxic Gas Release
    - 19.3. Fixed Fire Detection and Extinguishing Systems
    - 19.4. Fire water Systems
    - 19.5. Portable Fire Extinguishers
    - 19.6. H_2S Emergencies
20. First Aid
    - 20.1. Treatment
    - 20.2. Training
    - 20.3. First Aid Kits

Table 4.1 Representative Table of Contents for Safety Manual *(Continued)*

21. Hand and Power Tools
    - 21.1. Hand Tools
    - 21.2. Abrasive Wheel Machinery
    - 21.3. Pneumatic Tools
    - 21.4. Liquid Fuel Tools
22. Cranes, Chain Hoists, Sling Ropes
    - 22.1. Overhead Hoists
    - 22.2. Winch Trucks
    - 22.3. Wire Ropes, Chains, and Slings
    - 22.4. Tag Lines
    - 22.5. Lifting and Rigging
    - 22.6. Aerial Cages
    - 22.7. Critical Lifts
23. Excavations, Trenching, Shoring
    - 23.1. Safety Sign Requirements
    - 23.2. Permits
24. Simultaneous Operations
25. Pipelines
    - 25.1. Pipeline Locating and Repair
    - 25.2. Leak Repair on Shut-In Line
    - 25.3. Probe Rods
    - 25.4. Cold Leak Repairs on Live Lines
    - 25.5. Corrosion Probe/Injection Quill In-Service Removal
    - 25.6. Expandable Pipe Plugs
26. Offshore Operations
    - 26.1. Fueling Requirements
    - 26.2. Offshore Boat Use
    - 26.3. Helicopter Safety
    - 26.4. Personnel Baskets
27. Laboratories
    - 27.1. Process Analyzer Building Entry
    - 27.2. Use of Nitrogen
28. Office Safety

Each section contains rules that employees and contract workers are expected to follow. The following list contains a few representative items of such rules:

- Persons operating a vehicle (including boats) are not allowed to use mobile or cellular phones while driving.
- All injuries, accidents, near misses, and unsafe conditions should be reported immediately.

- Any equipment design or operating procedure problems that could create a hazardous situation should be reported immediately. These can include the following:
  - Cut or frayed electrical cords
  - Overloaded electrical outlets
  - Use of personal space heaters
  - Chemical or other spills
  - Exposed hot surfaces
  - Safety controls or devices that have been removed or bypassed
  - Nonfunctioning or missing warning or emergency signs and tags
  - Guards removed from rotating fans
  - Expired calibration and inspection dates on firefighting equipment
  - Material blocking stairways, aisles, or exits
  - Faulty or missing fire extinguishers
  - Tripping or falling hazards
  - Missing or outdated medical supplies
- Attendance at safety meetings is required.
- Personnel are not allowed to carry firearms, illegal drugs, or alcohol on to the work site.
- Follow the company's substance abuse policy.

BEHAVIOR-BASED SAFETY

A behavior-based safety (BBS) plan aims to make permanent changes in the manner in which people work. BBS is a process that helps employees identify and choose a safe behavior over an unsafe one. It also encourages employees to work with their colleagues on improving everyone's understanding of effective and ineffective behaviors as they apply to safety. Much of the change is brought about by observing how people work and identifying at-risk behaviors, along with those actions that merit positive feedback. If an unsafe behavior is observed, a nonthreatening discussion should follow. Problems are seen as opportunities to improve safety performance and to share concern, coach, and learn. All persons, including company workers and contractors, create a mind-set of "doing everything right."

The first step in the BBS process is to observe employees performing their routine tasks. Both safe and unsafe behaviors are noted and recorded (with personal information omitted). The observer provides positive feedback on safe behaviors and nonthreatening feedback on unsafe behaviors. Employees are provided with suggestions on correcting the unsafe or at-risk behaviors. The employees are not reprimanded or disciplined for at-risk behaviors, nor are any findings reported to management. Employees are encouraged to comment on the observations; their comments are included with observations themselves, along with any suggestions for improvement.

Results from the observation records are gathered and compiled in a single database. Reports from the database tell the BBS leaders as to which types of at risk behavior are most prevalent and in which locations they are taking place. Based on the insights generated during the review and analysis phase, recommendations for improvement can be made.

BBS should be a part of the company way of life. This means that if any employee notes that a colleague is demonstrating an at-risk behavior, then he or she is encouraged to talk to the colleague and suggest ways of changing that behavior.

OBSERVED HAZARD CARD

As part of their BBS program, many companies use an observed hazard card (also called a NEAR event or "STOP" card). An example is shown in Figure 4.1. The card is used to record observations of hazardous situations. If the employee considers the observed situation to present an immediate danger, he or she has the authority to stop the work until a review has been carried out.

Figure 4.1 is very simple. However, it does possess two features worthy of note. First, the person who completes the form is asked to suggest follow-up action. This is a request, not a requirement. Second, the card can be filled out anonymously. Nevertheless, employees should be encouraged to provide their names—the intent of the BBS program is to encourage open communication, not secret reporting.

<table>
<tr><th colspan="3">Complete this card if you are involved in, or if you witness a Potential Hazard or Near Miss Event</th></tr>
<tr><td>Date:</td><td>Time:</td><td>Location:</td></tr>
<tr><td colspan="3">Description of Hazard</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Suggested Follow-Up Action</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Name (optional)</td><td colspan="2"></td></tr>
</table>

FIGURE 4.1

Example of an "observed hazard" card.

FIVE-BY-FIVE POLICY

Another policy to do with behavior improvement is the "Five by Five" approach to maintenance. Before a person takes an action, he or she is encouraged to take five steps back and to take 5 minutes to mentally walk through the job before actually starting work. He or she will think through issues such as the following:

- Tools needed for the work
- Personal protective equipment requirements
- Other people in the area
- Competence to do the work
- Escape routes

LONE WORKER POLICY

When someone is working alone, the potential exists for that person to become trapped, injured, burned, or exposed to hazardous chemicals without having anyone on hand to help him. The injured person may not be able to raise the alarm or to ask for help. In order to minimize the risk associated with working alone, the following guidelines should be considered:

- The lone worker should always carry a radio tuned to the control room frequency. This allows him or her to call for help if he or she is able, and it allows the control room to make frequent checks on the worker's condition. (On the North Slope of Alaska, the control room calls outside workers frequently and on a schedule, such as once every 10 minutes. All the worker has to do is respond—thus proving that he or she is not injured.)
- The control room should keep a log of who is outside by themselves.
- The lone worker should describe what he or she is planning to do to the control room operators before going outside.
- When weather conditions are bad workers should not be alone.

INCIDENT REPORTING

It is essential that all incidents are reported promptly, and in detail—even those that have only minor consequences or that are first aid cases or that are near misses. In the United States, incidents that meet the OSHA guidelines for recordability must also be documented and reported. (The topics of Incident Investigation and Root Cause Analysis are discussed in *Process Risk and Reliability Management*).

For serious events such as multiple severe injuries or fatalities, each company will need to develop a reporting structure to determine which levels of management need to be informed about those events.

REPORTS

Incident reports should include the following as a minimum:

- Name of the company where the event occurred
- The location of the incident
- The time of the incident
- The number and severity of injuries
- A brief description of the incident

Vehicle incidents

Vehicle accidents (including boats) are a major cause of fatalities and injuries.

With regard to automobiles, the following can generally be excluded from a company's reporting process.

- The vehicle was legally parked
- The event occurred during the driver's normal journey to his or her normal place of work (commuting)
- Minor damage to as paint scratches or a stone hitting a windshield
- Vandalism or theft
- A company vehicle being driven on nonwork-related activities

Near misses

A near miss is an unplanned occurrence that interferes with or interrupts the orderly progress of work or has the potential to cause personal injury or monetary loss through property damage. In order to prevent a future occurrence that may result in an accident, a near miss incident reporting, analysis, and documentation system is a valuable accident prevention strategy.

Employees and contract workers should be encouraged to report all near miss incidents through the near miss hotline or web. The report does not need to be signed or contain any individual's name.

PORTABLE GAS DETECTORS

Portable gas detectors that clip on to a person's belt warn the wearer if he or she is being exposed to unacceptable levels of toxic gas. Probably the most common application in the process industries is for hydrogen sulfide (H_2S), but they can be used for other chemicals, such as hydrogen cyanide (HCN).

MACHINERY SAFETY

Machinery contains moving parts that can cause serious injury or death. Hence all accessible moving parts of machinery should be guarded. Guards may also be required for nonaccessible items such as chains, flywheels, pulleys, and belts because they could cause objects to fly through the air if they break. They are also sometimes used in circumstances where a leak could cause hot or toxic materials to spray into the environment. Guards—sometimes in the form of mesh—are also used to prevent people touching very hot or very cold surfaces. Some of the precautions to be taken when working with machinery are discussed below.

Machine guards should not create their own hazard. They should be free of burrs and sharp edges and should not create a tripping hazard. They should also be securely fastened and strong enough to support impact from failed machinery.

FALL PROTECTION

The following guidance can help minimize problems to do with fall protection:

- Fall protection equipment must be used when a worker could fall 2 meters or more.
- Fall protection capability should be integrated into the design of new and remodeled facilities.
- The maintenance department should be consulted regarding the location and suitability of anchor points.
- The anchor points must be capable of supporting a static load of 2,250 kilogram per person attached.
- Additional protective requirements may apply when the electric work is being carried out.
- Anchor points should be properly designed and engineered.

The OSHA standards to do with Fall Protection are 29 CFR 1926.500, 501, 502, and 503.

DEFINITIONS

The following definitions to do with fall protection are provided:

- *Personal Fall Arrest System*
  A system used to arrest an employee in a fall from a working level. It consists of an anchorage, connectors, a body harness, and may include a lanyard, deceleration device, lifeline, or combination of these items.
- *Safety Harness*
  The part of fall protection equipment, which supports the body in the event of a fall. A full body harness type is required—safety belts are not allowed for use as fall arrest equipment.
- *Lanyard*
  A flexible line of rope made from synthetic fibers having connectors at each end for connecting the body harness to a deceleration device, lifeline, or

anchorage. The lanyard shall not be attached by means of knots or loops. The lanyard shall have a double latch self-locking snap hook at each end for connecting the body harness to a lifeline or anchor point. Some lanyards may have a built-in deceleration device. A shock-absorbing lanyard is recommended because it imposes the minimum force to the body in the event of a fall.

- *Deceleration Device*
  Any mechanism such as a rope grab, self-retracting lifeline, or shock-absorbing lanyard, which serves to dissipate the force of the fall, which would otherwise be imposed on the employee.
- *Anchor Point*
  A secure point of attachment of lifelines, lanyards, or deceleration devices. Anchor points must be capable of supporting a static load of 5,000 pounds or 2,333 kg per person attached.
- *Working Height*
  The distance from the worker's footing to the next lower working level or surface to which an employee can fall.
- *Lifeline*
  A vertical line from a fixed anchorage or between two horizontal anchorages, independent of walking or working surfaces, to which a lanyard or fall arresting device is secured.
- *Competent Person*
  An individual knowledgeable of manufacturer's recommendations, instructions, and manufactured components who is capable of identifying existing and predictable hazards, and trained in the proper selection, use, and maintenance of fall protection.
- *Deceleration Distance*
  The vertical distance between the harness attachment point at the activation of the fall arrest equipment and that attachment point once the individual comes to a complete stop.

FALL PROTECTION SYSTEM

Examples where fall protection is required include, but are not limited to the following:

- Man-baskets
- Ladders when used as working platforms
- Incomplete structural steel
- Elevated piping or pipe racks (a horizontal lifeline system is recommended for elevated piperacks)
- Tank roof without standard guardrail system (regardless of work location)
- Open access ways for hoist area

- Building roofs (such as compressor and process buildings) without a 1070 mm continuous parapet at all sides.

Personnel fall arrest systems are not generally required in the following situations:

- Properly constructed scaffolds (completed only and when working inside the guardrail system)
- Roofs with a 1070 mm high, continuous parapet (or standard guardrail system)
- Stairways with standard railings
- Caged ladders
- Portable or scaffold ladders (only when used for access)
- Elevated walkways protected by guardrails

FALL ARREST SYSTEM EQUIPMENT

The following guidance is provided regarding the selection and maintenance of fall protection equipment:

- Personal fall arrest systems should limit free fall distance to 2 meters or less.
- The deceleration distance must be limited to 1 meter.
- The system should allow for an unobstructed fall and should not permit a swing fall hazard.
- All safety harnesses, lanyards, snap hooks, and other equipment must meet the material and assembly specifications, and testing requirements set forth in ANSI A-10.14 and OSHA 29 CFR 1926.502. Only approved fall protection devices may be used by personnel and must be worn as designated and as intended by the manufacturer. The key provisions are:
  - Connectors (Dee-rings and snap-hooks) shall have been proof-tested to 1600 kg and have a minimum tensile strength of 2,250 kg.
  - Only locking type snap hooks should be used.
  - Lanyards must have a minimum breaking strength of 2,250 kg and be constructed only from synthetic fibers.
  - The attachment point on the body harness (Dee-ring) shall be located in the center of the wearer's back near shoulder level or above the wearer's head.
- Each employee must visually inspect the personnel fall arrest system components prior to each use for wear, damage, and other deterioration.
- Personal fall protection systems and components that have been used to arrest a worker's fall should be immediately removed from service.

DROPPED OBJECTS

This section discusses the safety issues associated with small dropped objects, principally tools. Issues to do with large dropped objects in offshore operations are discussed in the book *Offshore Safety Management*.

Schueppert (2013) lists the precautions that those working at heights should follow. In addition to standard safety precautions, such as wearing a hard hat, it is important to:

- Stack materials to them to prevent sliding, falling, or collapse
- Barricade the drop zone below where the work is being done
- Use toe boards and debris nets as appropriate
- Put tools in a spill-control bucket
- Not to tether objects to a person—it may cause them to fall
- To use multipart tools that are designed to prevent inadvertent separation
- To secure tools such that they cannot fall to the level below.

Any time an object is dropped, the incident should be reported and analyzed as part of the incident reporting system.

COMPRESSED GAS CYLINDERS

Compressed gas cylinders should be secured in place on a regular cart or chained to a support in an upright position, that all cylinders not in use are protected with protective valve caps and that compressed oxygen and flammable gases are not be stored together, or near combustible materials, but stored in accordance with facility and industry safety procedures.

OVERHEAD POWER LINES

Regulatory guidance is provided in OSHA's 29 CFR 1926.550 Cranes and Derricks. The following guidelines should be considered when working with overhead power lines:

- Never touch an overhead line if it has been brought down by machinery or has fallen in a storm.
- Never assume lines are dead.
- De-energize equipment in the area.
- Ensure that the equipment remains de-energized by using a lockout/tag-out procedure.
- Use grounding lines as appropriate.
- Use insulating equipment.
- When working near overhead power lines, the use of nonconductive wooden or fiberglass ladders is recommended.
- Do not operate equipment around overhead power lines without appropriate permission.

- If an object such as a scaffold or crane must be moved in the area of overhead power lines, appoint a watcher whose sole responsibility is to observe the clearance between the power lines and the object.
- When a machine is in contact with an overhead line, do not allow anyone to come near or touch the machine.
- Never touch a person who is in contact with a live power line.
- Anyone in a vehicle that is in contact with an overhead power line should stay in the vehicle until the line is de-energized. If it is necessary to leave the vehicle due to fire jump out without touching any wires or the machine, keep both feet together, and hop to safety.
- Tools that are used by employees to handle energized conductors must be designed and constructed to withstand the voltages and stresses to which they are exposed.
- Use appropriate PPE. This equipment may consist of rubber insulating gloves, hoods, sleeves, matting, and blankets. These items must be inspected prior to each use and tested annually.
- Avoid storing materials under or near overhead power lines.

CRANES AND RIGGING

The lifting of heavy objects can be very hazardous, either because they can be dropped or because they can swing and strike a person or another piece of equipment. For example, one of the worst releases of hydrogen fluoride (HF) in the United States occurred at a refinery in Texas when a fired heater was being lifted. The crane dropped the load, shearing a nozzle on an HF storage tank.

Offshore, if a large equipment item such as a blowout preventor is dropped on to the deck of a platform or boat, serious damage can be done. If it is dropped in the water, it could hit a subsea pipe formation and create a major leak.

LIFTING PRECAUTIONS

Prior to carrying out a lift, the following precautions should be observed:

- All lifting equipment has been tested and inspected. In order to ensure that all lifting equipment has been tested within the prescribed time period, some companies use a color code. If the current color is blue, then only items that have a blue tag can be used.
- Personnel should be removed from the area of the lift path.
- All pipelines and equipment that could be affected by the lift should be adequately protected or bled down during the lift.
- All pipelines left in service must keep their shutdown devices in operation.
- No pig trap or launcher should be opened during lifting operations.
- All hot work in the area should be stopped while the lift is in progress.

CRANE OPERATION

The following precautions should be considered for crane operation:

- Installation of swing restriction devices
- Installation of video cameras in crane booms if out-of-sight lifts are to be performed
- Installation of monorails for repeat maintenance activities

Also, where possible, solid booms should be avoided since they are heavy and are strongly affected by the wind.

CHAPTER

5 Chemicals

CHAPTER OUTLINE

INTRODUCTION

This chapter describes some of the techniques that are used for classifying chemicals. Some of the chemicals that are commonly found in process facilities are discussed in more detail.

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FLUID CATEGORIES

The American Society of Mechanical Engineers (ASME) divides fluids into four categories, in decreasing order of severity:

A. Sour crude, sour gas, sour NGLs (natural gas liquids), sour produced water, sulfur dioxide (SO_2), some injection chemicals, and amines
B. Sweet crude, sweet gas, sweet NGLs, sweet produced water, glycol, injection chemicals, diesel, AvGas, methanol, exhaust, and heating medium
C. Solids (scale, NORM, wax), nitrogen, hydraulic fluid, and some injection chemicals
D. Water (potable, cooling, sea, black, gray, ballast, fire) and air.

The term “highly hazardous chemical” is also defined by the ASME in B31.3—1990 Chemical Plant and Petroleum Piping. They define a “Category M Fluid Service” as that service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid can produce serious, irreversible harm to persons even when prompt restorative measures are taken.

MATERIAL SAFETY DATA SHEETS

Information to do with the properties of hazardous chemicals is provided in Material Safety Data Sheets (MSDS), also known as Safety Data Sheets (SDS). They provide comprehensive information about the chemical that allows employers and workers to obtain concise, relevant, and accurate information that can be put in perspective with regard to the hazards, uses, and risk management of the chemical product in the workplace. The SDS should contain 16 sections. While there were some differences in existing industry recommendations, and requirements of countries, there was widespread agreement on a 16-section SDS that includes the following headings in the order specified:

1. Identification
2. Hazard(s) identification
3. Composition/information on ingredients
4. First-aid measures
5. Firefighting measures
6. Accidental release measures
7. Handling and storage
8. Exposure control/personal protection
9. Physical and chemical properties
10. Stability and reactivity
11. Toxicological information
12. Ecological information

13. Disposal considerations
14. Transport information
15. Regulatory information
16. Other information

Suppliers and generators of hazardous materials used in the workplace are required to document the specific hazards and related safety precautions and procedures. To do this, they generally create MSDSs. An MSDS contains information about chemical properties, health and physical hazards, first aid and medical treatment, emergency response, and the handling and disposal of chemicals. The MSDS should be concise, and immediately accessible and usable. MSDSs are available for chemical products from all U.S. and most European suppliers or manufacturers.

Chemicals that require an MSDS include the following:

- Treating chemicals
- Laboratory chemicals/solvents
- Industrial cleaning agents
- Bulk solvents/thinners/paints
- Crude oil, natural gas, and other process streams
- Fuels such as jet, gasoline, and diesel

MSDS should be made available to all affected employees and contractors at work locations, field offices, or control rooms. MSDSs have to be provided not only for the principal products and materials used in a process but also for any chemical that may be present on site, even if the quantities are small. Therefore, a large facility may possess a library of thousands of MSDS.

For companies operating in the United States, the design, content, and application of an MSDS are explained in detail in Occupational Safety and Health Administration (OSHA)'s 1910.1200 (g) Hazard Communication Standard (HCS). Some of the key points with regard to this four page standard are as follows:

- The manufacturer and/or distributor of a chemical is responsible for writing and distributing the MSDS.
- The MSDS must contain information describing the hazardous properties of the chemical.
- The MSDS must also describe flammability and explosive properties of the chemical.
- First aid and other treatment measures should be described.
- A name and address of where more information can be obtained, if needed.

The MSDS should provide the following information on the hazardous chemicals:

- The chemical's physical status—e.g., whether the phase is solid, liquid, or gas.
- The chemical reactivity of the hazardous chemical, both when isolated and when mixed with other chemicals in the process, or with air that might enter the system.

- Information regarding the corrosivity of the various streams should be supplied. If an operator is provided with a new type of sample container, e.g., there should be information which tells him whether the material is safe.

OSHA provides the following guidance with respect to MSDS:

Chemical manufacturers and importers are required to obtain or develop a material safety data sheet for each hazardous chemical they produce or import. Distributors are responsible for ensuring that their customers are provided a copy of these MSDSs. Employers must have an MSDS for each hazardous chemical which they use. Employers may rely on the information received from their suppliers. The specific requirements for material safety data sheets are in paragraph (g) of the standard...

The role of MSDSs under the rule is to provide detailed information on each hazardous chemical, including its potential hazardous effects, its physical and chemical characteristics, and recommendations for appropriate protective measures. This information should be useful to you as the employer responsible for designing protective programs, as well as to the workers. If you are not familiar with material safety data sheets and with chemical terminology, you may need to learn to use them yourself. A glossary of MSDS terms may be helpful in this regard. Generally speaking, most employers using hazardous chemicals will primarily be concerned with MSDS information regarding hazardous effects and recommended protective measures. Focus on the sections of the MSDS that are applicable to your situation.

MSDSs must be readily accessible to employees when they are in their work areas during their workshifts. This may be accomplished in many different ways. You must decide what is appropriate for your particular workplace. Some employers keep the MSDSs in a binder in a central location (e.g., in the pickup truck on a construction site). Others, particularly in workplaces with large numbers of chemicals, computerize the information and provide access through terminals. As long as employees can get the information when they need it, any approach may be used. The employees must have access to the MSDSs themselves—simply having a system where the information can be read to them over the phone is only permitted under the mobile worksite provision, paragraph (g)(9), when employees must travel between workplaces during the shift. In this situation, they have access to the MSDSs prior to leaving the primary worksite, and when they return, so the telephone system is simply an emergency arrangement.

When conducting an inspection, OSHA looks for the following information to do with MSDS:

- Designation of person(s) responsible for obtaining and maintaining the MSDSs
- How the sheets are to be accessed and kept up to date in the workplace
- Procedures to follow when the MSDS is not received at the time of the first shipment

- For producers, procedures to update the MSDS when new and significant health information is found
- Description of alternatives to actual data sheets in the workplace, if used

For employers using hazardous chemicals, the most important aspect of the written program in terms of MSDSs is to ensure that someone is responsible for obtaining and maintaining the MSDSs for every hazardous chemical in the workplace. The list of hazardous chemicals required to be maintained as part of the written program will serve as an inventory. As new chemicals are purchased, the list should be updated. Many companies have found it convenient to include on their purchase orders the name and address of the person designated in their company to receive MSDS.

Within the United States, there is no regulation as to how often MSDSs should be updated or revalidated. Canadian law requires that this be done at least every 3 years; this update frequency is often used as a good practice, even when it is not the law.

OSHA states the following regarding storing MSDS in electronic format only:

> *If the employee's work area includes the area where the MSDSs can be obtained, then maintaining MSDSs on a computer would be in compliance. If the MSDSs can only be accessed out of the employee's work area(s), then the employer would not be in compliance with 1910.1200(g)(8) or (9) and 1926.59 (h)(1)(i–v).*

GLOBAL HARMONIZATION SYSTEM

Currently many different countries have their own standards for chemical hazard classification and communication. The Globally Harmonized System of Classification and Labeling of Chemicals (GHS) is intended to replace these multiple systems with one uniform system.

GHS is an internationally agreed upon system set to replace the various different classification and labeling standards used in different countries. The system, whose development started in the year 1992, supersedes the pertinent European and U.S. standards. Its goals are to:

- Provide an internationally comprehensible system for hazard communication, hazard classification, and labeling.
- Provide a framework for those countries without an existing system.
- Facilitate international trade in chemicals whose hazards have been properly assessed and identified on an international basis.
- Reduce the need for animal testing and evaluation of chemicals.

GHS uses a common and consistent approach to defining and classifying hazards, and to communicating hazard information on labels and SDS. It covers all hazardous chemicals and products, including mixtures, and classifies them according to their physical, health, and environmental hazards.

The GHS is not a regulation. Therefore, compliance with the GHS is voluntary for each country but companies in countries that do not adopt the GHS will be at a disadvantage when doing business internationally. The GHS guidance, also known as "The Purple Book," establishes criteria and methods for hazard classification and communication. It provides countries with the regulatory framework to develop or modify existing programs. The data used for classification may be obtained from tests, literature, and practical experience. The main elements of the hazard classification criteria are summarized below.

There is no international implementation schedule for the GHS. In the United States, the OSHA has revised its HCS so as to be in alignment with the GHS system. The HCS will be fully implemented in 2016.

THE SAFETY DIAMOND

NFPA (2007) defines the "fire or safety diamond" used by emergency personnel to quickly and easily identify the risks posed by nearby hazardous materials. It is also used within process facilities, particularly in storage areas and tank farms.

The fire diamond has four color-coded sections, as illustrated in Figure 5.1. The blue, red, and yellow fields correspond to chemical's effect on health, flammability, and reactivity, respectively. They all use a numbering scale ranging from 0 to 4. A value of 0 means that the material poses essentially no hazard; a rating

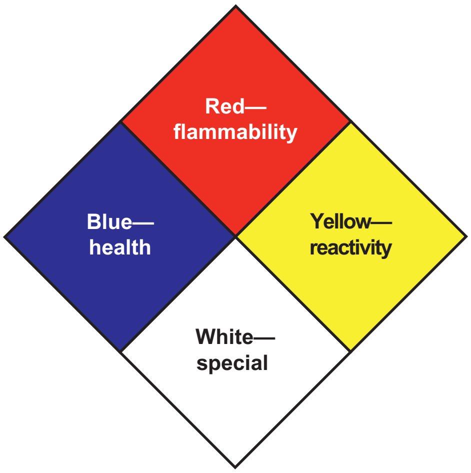

FIGURE 5.1

Safety diamond.

of 4 indicates extreme danger. Table 5.1 provides further description of the numbering system for the first three fields.

The fourth field is white; its use tends to be more variable than the other three, both in meaning and in what letters or numbers are written there. It can contain symbols such as:

- ~~**W**~~: reacts with water in an unusual or dangerous manner.
- **OX** or **OXY**: oxidizer.
- **COR**: Corrosive.
- **ACID** and **ALK**: strong acid or base.
- **BIO**: Biological hazard.
- **POI**: Poisonous.
- : Radioactive.
- **CRY** or **CRYO**: Cryogenic

Table 5.1 Safety Diamond Numbering System

	Flammability (Red)	Reactivity (Yellow)	Health (Blue)
4	Will rapidly or completely vaporize at normal atmospheric pressure and temperature, or is readily dispersed in air and will burn readily.	Readily capable of detonation or explosive decomposition at normal temperatures and pressures.	Very short exposure could cause death or major residual injury.
3	Liquids and solids that can be ignited under almost all ambient temperature conditions. Flash point below 38°C (100°F) but above 23°C (73°F).	Capable of detonation or explosive decomposition but requires a strong initiating source, must be heated under confinement before initiation, reacts explosively with water, or will detonate if severely shocked.	Short exposure could cause serious temporary or moderate residual injury.
2	Must be moderately heated or exposed to relatively high ambient temperature before ignition can occur. Flash point between 38°C (100°F) and 93°C (200°F).	Undergoes violent chemical change at elevated temperatures and pressures, reacts violently with water, or may form explosive mixtures with water.	Intense or continued but not chronic exposure could cause temporary incapacitation or possible residual injury.
1	Must be preheated before ignition can occur. Flash point over 93°C (200°F).	Normally stable but can become unstable at elevated temperatures and pressures.	Exposure would cause irritation with only minor residual injury.
0	Will not burn.	Normally stable, even under fire exposure conditions, and is not reactive with water.	No health hazard.

EXPOSURE LIMITS

Information to do with the effect of a chemical on human beings is provided in MSDS as discussed in Chapter 5. The U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) Lookup Tables provide further guidance. Other sources of information include the following:

- ANSI (American National Standards Institute)
- API (American Petroleum Institute)
- ASME
- Dangerous Properties Of Industrial Materials, van Nostrand Reinhold
- Emergency Action Guides, Association of American Railroads
- NFPA (National Fire Protection Association)
- Handbook of Chemistry & Physics, CRC Press
- Hazardous Chemical Desk Reference, van Nostrand Reinhold
- Merck Index, Merck Company
- NIOSH/OSHA Pocket Guides to Chemical Hazards
- Chemical Engineers Handbook, McGraw-Hill

When discussing exposure to toxic gases, the phrase "short term" is generally taken to be a time period of 60 minutes or less. Short-term limits are usually concerned with worker safety (although the Bhopal incident is a major exception to this generalization). It is generally assumed that exposure occurs through inhalation through the lungs (toxic materials can also be absorbed through the linings of the eyes, mouth, and throat).

Exposure limits are usually measured either in parts per million (ppm) by volume or micrograms per cubic meter of air ($\mu g/m^3$). Concentrations can be converted from $\mu g/m^3$ to ppm by volume at 20°C by multiplying the value by (24.04/MW), where MW is the molecular weight of the gas.

Various short-term exposure limits (STELs) values are in use. They include the following:

- ERPG—Emergency Response Planning Guidelines
- PEL—Permissible Exposure Limits
- TLV—Threshold Limit Value
- STEL
- IDLH—Immediately Dangerous to Life and Health

Regardless of which method is used, it is important to recognize that large differences exist between individuals regarding their response to exposure to toxic gases.

EMERGENCY RESPONSE PLANNING GUIDELINES

ERPGs are widely used. As defined by *The American Industrial Hygiene Association*, ERPGs (AIHA 2009) provide estimates for concentration ranges "where a person may reasonably anticipate observing adverse effects as a consequence of exposure to the chemical in question."

Three ERPG values are provided for each of the substances that have been researched:

1. ERPG-3—The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.
2. ERPG-2—The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.
3. ERPG-1—The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

ERPG values for some widely used chemicals are provided in Table 5.2.

Workers at process facilities are generally quite healthy and they know what to do and where to go in the event of an emergency. Hence there is not usually a justification for using very conservative exposure limit values for short-term exposure to a toxic gas release. For this reason, the ERPG-2 value can be used for workers rather than the ERPG-3 level. ERPG-3 is more useful when considering members of the public, some of whom could be in ill health, and others of whom could have trouble evacuating the affected area.

A key feature of all ERPG levels is that exposure is measured over a period of 1 hour. In practice, a worker who is exposed to one of these chemicals is not going to stay in the same place for an hour; he or she is going to move to a safe place (assuming that he is conscious and mobile).

Table 5.2 ERPG Values (ppm by Volume)

Chemical	Formula	ERPG		
		1	2	3
Ammonia	NH_3	1,000	200	25
1,3 Butadiene		5,000	500	10
Chlorine	Cl_2	20	3	1
Ethylene oxide	C_2H_4O	500	50	N/A
Hydrogen chloride	HCl	100	20	3
Hydrogen fluoride	HF	50	20	5
Hydrogen sulfide	H_2S	100	30	0.1
Methanol	MeOH	5,000	1,000	200
Phosgene	$COCl_2$	1	0.2	N/A
Sulfur dioxide	SO_2	15	3	0.3
Vinyl acetate		500	75	5

IMMEDIATELY DANGEROUS TO LIFE AND HEALTH

The IDLH concentration value (NIOSH 1985) is defined as:

> *The maximum concentration from which... one could escape in 30 minutes without experiencing any escape-impairing or irreversible health effects.*

IDLH is intended to provide guidance for determining respiratory protection requirements in occupational environments; it is not necessarily suitable for emergency planning and risk assessment. However, IDLH information is often the only form of exposure information available. IDLH values are often found in MSDS and in standard references. Some practitioners use a value of IDLH/10 as a working number for defining acceptable risk.

Table 5.3 provides IDLH values for some of the more common toxic chemicals. (For reference, the ERPG-2 values are also shown; typically they are much lower than the IDLH levels.)

PERMISSIBLE EXPOSURE LIMITS

The U.S. OSHA sets PELs to protect workers against the health effects of exposure to hazardous substances. PELs are based on an 8-hour time-weighted average (TWA) exposure.

THRESHOLD LIMIT VALUES

TLVs are guidelines (not standards) prepared by the American Conference of Governmental Industrial Hygienists (ACGIH) to assist industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace. TLV incorporates the PEL values already described. However, it also incorporates an STEL and an absolute upper limit. A TLV reflects the level

Table 5.3 IDLH Values (ppm by Volume)

Chemical	Formula	IDLH	ERPG-2
Carbon monoxide	CO	1,200	350
Chlorine	Cl_2	10	3
Ethylene oxide	C_2H_4O	800	50
Hydrogen chloride	HCl	50	3
Hydrogen fluoride	HF	30	20
Hydrogen sulfide	H_2S	100	30
Methanol	CH_3OH	6,000	1,000
Phosgene	$COCl_2$	2	0.2
Sulfur dioxide	SO_2	100	3

of exposure that the typical worker can experience without an unreasonable risk of disease or injury.

TLVs can be measured in one of three ways: TLV-TWA, TLV-STEL, and TLV-C. TLV-TWA represents the concentration to which a worker can be exposed for 8 hours per day, 40 hours per week without suffering adverse health effects. This is equivalent to the PEL-TWA, already described. No more than four excursions per day are permitted with at least 60 minutes between excursions and provided that the 8-hour TLV-TWA is not exceeded.

TLV-STEL represents the maximum concentration of the chemical to which the worker can be exposed for up to 15 continuous minutes without suffering from one or more of the following:

- Intolerable irritation
- Chronic or irreversible tissue damage
- Narcosis of sufficient degree to increase accident proneness (narcosis affects a person's judgment and can impair their ability to work safely). No more than 4 excursions per day are permitted with at least 60 minutes between excursions and provided that the 8-hour TLV-TWA is not exceeded

TLC-C (Ceiling) represents the concentration which should not be exceeded, even instantaneously. This is usually the one of most interest in safety work.

SHORT-TERM EXPOSURE LIMIT

STEL is a U.K. term that sets the maximum concentration to which a person can be exposed for a 15-minute period.

BENZENE

Benzene is used in the manufacture of many different industrial chemicals, including plastics, detergents, and insecticides. It is a carcinogen that can cause leukemia and other illnesses.

OSHA regulations have established a PEL of 1.0 ppm, as an 8-hour TWA and a 15-minute STEL of 5.0 ppm. The OSHA regulation contains an action level of 0.5 ppm 8-hour TWA, which triggers requirements for additional monitoring, medical surveillance, and annual employee training.

The standard exempts containers and pipelines carrying mixtures with less than 0.1% benzene and natural gas processing plants processing gas with less than 0.1% benzene. Also exempted are work operations where the only exposure to benzene is from liquid mixtures containing less than 0.1% benzene and oil and gas drilling, production, and servicing operations. These exempted operations still fall under the OSHA 1910.1000 PELs of 10 ppm PEL or 25 ppm ceiling.

One company has elected to voluntarily impose 1.0 ppm PEL and 5.0 ppm STEL across all of its operations.

HYDROGEN FLUORIDE

Hydrogen fluoride (HF) has many industrial uses. In the process industries, it is used in many refineries as an alkylation catalyst (the alternative is sulfuric acid). The HF arrives either by tank car or truck. It is loaded into a storage tank, from where it is fed on a continuous basis.

Upon contact with moisture, including tissue, HF immediately converts to hydrofluoric acid, which is highly corrosive and toxic, and requires immediate medical attention upon exposure.

The safe handling of HF requires that monitors be posted at critical locations and that all workers wear the correct level of PPE (personal protective equipment). Disposable PPE should be neutralized before being placed in refuse containers.

Issues to watch for with regard to HF include the following.

UNLOADING

The process of unloading an HF truck or tank car can be very hazardous were there to be a hose rupture or other event leading to a spill. This activity must be thoroughly controlled through the use of detailed procedures and all persons must have the highest level of training. They must also wear the correct PPE to protect themselves should there be a release.

KOH BEDS

Product streams from the alkylation unit contain trace amounts of HF. The HF is removed by flowing the liquid through a vessel containing a bed of solid potassium hydroxide (KOH). The HF reacts with the KOH to produce potassium fluoride and water.

If there is a major process upset resulting in high concentrations of HF in the product streams, the reaction with the KOH bed can become extremely exothermic. There have been cases where the sudden increase in pressure overwhelmed the relief valve of the vessel and the KOH Treater ruptured. Therefore, in addition to having a high level of safety instrumentation, the process should be designed for an HF breakthrough.

One way of doing this is to make sure that the liquid stream flows down the KOH Treater. In earlier designs, the liquid flowed up. That meant that, were the relief valves on the vessel to open the resulting low pressure would suck more HF into the vessel where it would flow over the KOH bed resulting in an even more violent reaction.

DEDICATED FLARE

Alkylation units generally have their own flare systems because the gases that go to the flare are acidic. Hence they could cause severe corrosion of the normal flare system. The HF flare and its associated piping are also subject to corrosion. Therefore, the system has to be shut down on a regular basis for maintenance. Operating the alkylation during the maintenance period requires extreme caution and vigilance.

SULFUR DIOXIDE

Sulfur is present in many raw materials, including crude oil, coal, and metal ores. Sulfur oxide (SO_x) gases are formed when fuel-containing sulfur, such as coal and oil, is burned, or when metals are extracted from ore. SO_2 dissolves in water vapor to form sulfurous and sulfuric acids; it also interacts with other gases and particles in the air to form sulfates and other products that can be harmful to people and their environment. In particular, SO_2 is the principal cause of acid rain, which leads to deforestation, damage to buildings, and the acidification of waterways.

SO_2 is not flammable, and there is no evidence of health effects for chronic, long-term exposure.

Limits for SO_2 emissions are set by many agencies, including the EPA, the Minerals Management Service (MMS), and the World Bank/International Finance Corporation (IFC). The IFC prohibits the dilution of emissions prior to discharge into the atmosphere.

The National Ambient Air Quality Standards for SO_2 are given in Table 5.4.

With regard to offshore operations, SO_2 can be a potential health (as distinct from safety) issue. Generally, the on-board turbines are powered by a slip stream from the gas produced by the well. If the fuel gas contains sulfur compounds, they will be oxidized to create SO_2, which will be released continuously, thus creating a potential health problem.

The health effects of SO_2 are given in Table 5.5.

Two values for safe working limits are provided. The American Conference of Industrial Hygienists (ACGIH) provides a value of 2 ppm for an 8-hour work exposure. The National Institute for Occupational Safety and Health (NIOSH) provides a value of 5 ppm for an 8-hour work exposure.

SO_2 monitors generally have a set point of 2 ppm.

Table 5.4 NAQ Sulfur Dioxide Standards

Time Measurement	Standard (ppm)	Standard (g/m^3)
Annual arithmetic mean	0.03	80
24-hour average	0.14	365
3-hour average	0.50	1,300

Table 5.5 Health Effects of Sulfur Dioxide (Typical)

Concentration (ppm)	Potential Effect
0.3	Odor detection
2–5	Impact on lung function (variable)
6–12	Nose, throat irritation, nosebleeds
20	• Eye irritation • More severe respiratory symptoms
50–100	60 minutes maximum tolerable exposure
>100	Loss of consciousness, respiratory arrest, cardiac arrest, death

1 ppm = 1.4 mg/m^3.

HYDROGEN SULFIDE

Hydrogen sulfide (H_2S) is a highly toxic chemical compound that is found in a wide variety of oil processing operations. High concentrations of H_2S may be present in crude oil, molten sulfur, tank and pit-bottom sludge, and produced water, all of which may release H_2S when agitated, heated, or depressurized. Typical operational activities where personnel may be exposed to H_2S include drawing samples, handling and testing samples, gauging tanks, and when opening lines and equipment. Typical maintenance activities where personnel may be exposed to H_2S include tank cleaning and repair, vessel or sump clean-outs and repair, and well maintenance. These and other similar activities may place workers at a higher risk of exposure to H_2S.

TOXICITY

Exposures to H_2S at concentrations as low as 600 ppm can cause death in a matter of minutes due to paralysis of the respiratory system. The gas is colorless and flammable. It is also 19% more dense than air. Therefore any H_2S that leaks is likely to accumulate at a low point such as pits, trenches, enclosed well bays and cellars, sumps, the tops of floating roof tanks, buildings, shale shakers and portable containers. H_2S is soluble in many liquids, including hydrocarbons. However, H_2S mixed with natural gas may form a lighter-than-air mixture. In general, the fact that H_2S is "heavier than air" is a statement that should be used with care, particularly when concentrations of the gas are low (say less than 100 ppm).

Table 5.6 summarizes the effects of H_2S at various concentration levels. (Guidance regarding the management of H_2S offshore is provided in API RP 14C.)

H_2S oxidizes rapidly in the body; therefore, there are normally no permanent aftereffects from acute exposure if the victim is rescued promptly and resuscitated before experiencing prolonged oxygen deprivation.

H_2S is not a known carcinogen.

Table 5.6 Health Effects of Hydrogen Sulfide (Typical)

Concentration (ppm)	Potential Effect
<10	Not a health concern.
10–20	Eye and respiratory irritation.
20–100	Inflammation, corneal blistering, and opacity of the eye, loss of the sense of smell, headache, cough, and nausea.
100–300	Respiratory difficulty.
300–600	Central and peripheral nervous system effects, i.e., tremors, weakness, numbness of extremities, unconsciousness, and convulsions.
600–1,000	Rapid unconsciousness, death if first aid not promptly administered.
>1,000	Death.

1 ppm = 1.4 mg/m^3.

Hydrogen sulfide H_2S is easily detected by sense of smell up to values of around 100 ppm. (Most texts state that H_2S smells like rotten eggs, but, with modern refrigeration, it is probably more apropos to state that rotten eggs smell like H_2S.) Above the value of 100 ppm "olfactory fatigue" can set in, and a person becomes unable to smell the gas. Therefore, the inability to detect H_2S through the sense of smell does not prove that the gas is not present. Moreover, the ability to detect the gas by smell varies widely among individuals. Hence portable H_2S detectors are commonly used. Each person at the site carries one of these devices, which is typically set to alarm at a value of 10 ppm. In addition to the personal alarms, fixed sensors located around the facility will warn of a release. These sensors should send their signal to the control room.

FLAMMABILITY

H_2S has a wide flammable range (4.3%–45.5% by volume in air). When burned, H_2S forms SO_2. In an oxygen-deficient atmosphere, iron and steel will react with H_2S to form iron sulfide deposits on the surface of the metal.

LOCATION OF MONITORS

API RP 14C provides the following guidance for the location of H_2S monitors for offshore installations:

- Atmospheric H_2S concentration is >50 ppm
- H_2S concentration in piping is >100 ppm
- Enclosed areas as defined by API RP500 where H_2S could reach >50 ppm

- Poorly ventilated areas
- Sensors should be no greater than 36 inches above the floor/deck with a grid pattern of at least one detector per 400 square feet (37 square meter) of floor space
- Sleeping quarters
- Within 10 feet of applicable equipment:
  - Vessels
  - Compressors (> 50HP/38 KW should have two monitors)
  - Pumps
  - Headers
  - Wellheads

If H_2S is detected both visual and audible alarms should be triggered.

CORROSION

H_2S can cause corrosion of stainless steels such as 316 and 410 stainless in the form of sulfide stress cracking. (Other factors, such as pH, chloride concentration, and temperature also affect the potential for steel cracking.) Copper alloys corrode rapidly in H_2S service. An industry value that has been developed is NACE MR-01, 2003, from the National Association of Corrosion Engineers. In the gas phase, a stream is sour if the H_2S partial pressure exceeds 0.05 psia. If a single phase liquid is in equilibrium with a gas phase, where the gas phase H_2S partial pressure exceeds 0.05 psia, then that liquid is also considered to be sour. If the liquid is not in equilibrium with the gas phase, then the liquid is considered sour, if this bubble point gas phase H_2S partial pressure exceeds 0.05 psia. The presence of water is not required for a gas and/or liquid to be considered to be sour, nor is there a minimum pressure to avoid designating a gas or liquid as sour.

In an oxygen-deficient atmosphere, iron and steel will react with H_2S to form iron sulfide deposits on the surface of the metal. Some iron sulfides (known as pyrophoric iron sulfide) are unstable and, when exposed to air, will undergo a rapid chemical reaction creating an ignition source that should be considered during equipment shutdowns.

H_2S is easily detected by sense of smell up to values of around 100 ppm. (Most texts state that H_2S smells like rotten eggs, but, with modern refrigeration, it is probably more *apropos* to state that rotten eggs smell like H_2S.) Above the value of 100 ppm "olfactory fatigue" can set in, and a person becomes unable to smell the gas. Therefore, the inability to detect H_2S through the sense of smell does not prove that the gas is not present. Moreover, the ability to detect the gas by smell varies widely among individuals.

Portable H_2S detectors are commonly used wherever H_2S may be present. They typically have an alarm value set in the 5–10 ppm range. In addition to the personal alarms, fixed sensors located around the facility will warn of a release.

CHLORINE

Chlorine (Cl_2) is widely used to treat cooling water on process facilities. It is frequently stored under pressure as a liquid in 1-ton containers. (A leak from the liquid section of the container will be around 15 times greater than from a similar size hole in the vapor space.)

Chlorine loading/storage facilities and chlorine addition systems should, where possible, be located remotely. Alternatively, the chlorine containers can be located near, and on the normal upwind side of, cooling towers so that a leak can be flow directly into the cooling water system. The containers themselves should be protected from impact by vehicles. When the containers are transported, they should be well secured. Chlorine containers should not be stored near a heat source, anhydrous ammonia, hydrocarbons, or any chemicals with which it could react violently.

In the event of a container leak or a liquid spill, water should not be sprayed directly on to the liquid. Water sprayed on to the liquid will increase the vaporization rate and will form highly corrosive hydrochloric acid that could then increase the size of the leak. Therefore, the water should be sprayed into the chlorine vapor space.

CARBON MONOXIDE

If a fired heater, or some other combustion equipment, malfunctions, it could create carbon monoxide (CO), which is a toxic gas that has no smell. Therefore, it is useful to install CO detectors where personnel are present, or at the suction to ventilation and air-conditioning systems. If the instrument detects an unacceptably high level of CO, the signal can be used to shut down the air-conditioning system.

CARBON DIOXIDE

Carbon dioxide (CO_2) is found in many gas streams in industrial facilities—often in quite high concentrations. Although it is not toxic, it can cause asphyxiation. And, like nitrogen, its danger is exacerbated by the fact that it has no odor.

Even though CO_2 will not burn, its presence can affect the flammability range and characteristics of the hydrocarbons with which it is mixed. (It will generally reduce both the lower and upper flammability limits.) Also, the high concentrations of CO_2 in air that are likely to be present during a major fire may affect the performance characteristics of the diesel motors used to drive the firewater pumps.

If CO_2 is stored as a liquid, its release will result in very low temperatures that could lead to brittle fracture of structures.

NITROGEN

Nitrogen is not, in and of itself, hazardous. After all 79% of air is nitrogen. And it is widely used as an inert gas to suppress potential fires and explosions.

Nevertheless, nitrogen does pose at least two significant hazards. The first is that a breathing air supply is fed from a nitrogen header or bottle rather than an air header. A person breathing the nitrogen will expire very quickly. (A variation on this theme is the inadvertent use of nitrogen in instrument systems. If the instruments are in a small room, then the nitrogen that vents from those instruments can gradually reduce the oxygen concentration in the room, leading to the potential for asphyxiation of the room's inhabitants.)

A second hazard associated with nitrogen is the possibility that it may be inadvertently used as the source of combustion air to a fired heater. The reduced oxygen in the air supply could cause the heater's flame to go out, thus creating the potential for a confined vapor cloud explosion.

If a person enters an atmosphere of nitrogen, he or she can lose consciousness without any warning symptoms in as little as 20 seconds. Death can follow in 3–4 minutes. One deep breath of 100% nitrogen will be fatal because breathing is stimulated and controlled by the concentration of carbon dioxide in the lungs; 100% nitrogen displaces the carbon dioxide completely, so breathing stops. (Further discussion to do with the hazards of nitrogen is provided in Chapter 17.)

Personnel should not work in or enter atmospheres containing less than 19.5% oxygen, unless equipped with a self-contained breathing apparatus or breathing air mask. This is also true of rescue personnel who can be overcome by the same oxygen-deficient atmosphere as the initial victim.

Particular care must be taken if nitrogen is used as a temporary backup for instrument air or plant air for the following reasons:

- If the gas is discharged from the instrument or air vent into a confined space such as a building, the concentration of oxygen could fall to a hazardous level (generally set at 19.5%). This problem is a particular concern in small spaces such as control rooms, instrument cabinets, and analyzer rooms.
- The nitrogen could be contaminated with instrument or plant air.
- It could be inadvertently used for supplied-air respirators.

The following precautions should be taken when using nitrogen:

- Its use as a backup for instrument or plant air is always as a temporary supply. It must never be permanently connected or hard-piped to an air system.
- Once the normal air supply is restored, the temporary nitrogen connection should be disconnected immediately.

- The nitrogen supply must be continuously tested for purity, particularly for oxygen content.
- Utility stations in a nitrogen distribution system must be clearly identified. Special connectors and hoses which are not common to any other system should be used.
- Special procedures to do with the use of nitrogen should be written, and all workers, including contract workers, should be trained in the use and hazards of nitrogen.
- Where a permanent connection of nitrogen is not required for safety or process reasons, it should be disconnected or blinded when not in use.

LEAD

Lead exposures can arise from certain work activities, including removing paint from surfaces coated with lead-containing paint. Lead-containing dust and fumes can be generated by flame-torch cutting, welding, heat guns, sanding, scraping, and grinding of lead painted surfaces. Lead may also be used in soldering. Respirators can be used to protect against lead fumes, but, as always, engineering controls should always be used where possible.

Guidance to do with the management of lead is provided by OSHA, Department of Labor: 29 CFR 1910.1025 and 1926.62.

The PEL for lead is 50 micrograms per cubic meter of air as an 8-hour TWA concentration. The acceptable limits used by some companies for training, medical surveillance, respirator fit testing, and exposure monitoring is 30 micrograms per cubic meter 8-hour TWA.

Materials containing lead at a concentration greater than 5.0 milligrams per liter should be considered as being hazardous waste.

CHAPTER

Personal protective equipment

6

CHAPTER OUTLINE

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INTRODUCTION

Personal protective equipment (PPE) is a clothing or equipment worn by workers to protect them from fire, exposure to toxic chemicals and direct impact. PPE should only be used when engineering designs and operating or maintenance practices do not provide a sufficiently safe work environment.

The need for PPE can be determined with a risk analysis, which will be structured along the following lines:

1. Can the hazard be removed? If so, there will be no need for PPE.
2. Can the consequences of the hazard be reduced? If so, it may be possible to work with a lower level of PPE.
3. Can the likelihood of occurrence be reduced? This may not change PPE requirements, but it will reduce the chance of someone being injured.

Only when the above analysis has been completed, should consideration be given to the types of PPE to be used. A job hazards analysis (JHA), as described in Chapter 2, will help determine what type of PPE is needed and when and where it should be worn.

EMPLOYER RESPONSIBILITY

In general, it is the responsibility of the employer to provide the PPE that workers need (OSHA 2003) and to maintain or repair it as needed. The employer must also provide workers with the training to use the PPE that has been provided and make sure that the workers know how to take care of the PPE.

REGULATIONS AND STANDARDS

There is a plethora of regulations and standards to do with PPE. Some of them are listed below:

- *General*
  - OSHA 3151-12R.2003
  - OSHA 29 CFR 1910.132
  - OSHA 29 CFR 1926.95
- *Clothing*
  - NFPA 70E
- *Eye and Face Protection*
  - OSHA 29 CFR 1910.132
  - OSHA 29 CFR 1910.133

- OSHA 29 CFR 1915.152 (shipyards)
    - OSHA 29 CFR 1926.102
- *Head Protection*
    - ANSI Z89.1
    - OSHA 29 CFR 1910.135
    - OSHA 29 CFR 1926.100
    - OSHA 29 CFR 1915.155
- *Foot Protection*
    - OSHA 29 CFR 1910.136
    - OSHA 29 CFR 1926.96
    - ANSI Z41.1
    - OSHA 29 CFR 1915.156
- *Electrical Protective Devices*
    - OSHA 29 CFR 1910.137
- *Hand Protection*
    - OSHA 29 CFR 1910.138
    - OSHA 29 CFR 1915.157
- *Hearing*
    - OSHA 29 CFR 1926.101
    - OSHA Publication 3074
- *Respiratory*
    - OSHA 29 CFR 1910.134
    - OSHA Publication 3079

CLOTHING

Proper clothing will help keep acidic, corrosive, oily, dirty, or dusty materials off the body. Even if clothing with special PPE capabilities is not required, the following rules should be observed at all times and in all work site locations.

- Shorts are never permitted. Workers should always wear full-length pants (trousers) that cover the entire leg.
- Full cover shoes should always be worn. They should have nonslip soles. Many companies require that shoes always have toe protection—often in the form of a steel toe cap.
- Hard hats should always be worn.

The effectiveness of clothing with regard to safety and health is affected by the following three factors:

1. *Insulation*. High insulation is generally desired in cold weather and not wanted when temperatures are high.

2. *Permeability*. This is the measure of the resistance to water vapor movement throughout the clothing.
3. *Ventilation.* The ability of ambient air to move throughout the fabric itself or through garment openings.

If special clothing is required, then the type of clothing selected depends upon the nature of the hazard.

FLAME-RESISTANT CLOTHING

If normal clothing catches fire, it will continue to burn even if the ignition source is removed or if the affected worker moves away from the fire. Flame-resistant material self-extinguishes on removal of the ignition source. Clothing made of flame-resistant material is known as flame-resistant clothing (FRC), which will not continue to burn in such situations, nor will it melt like some synthetic fabrics. It is used to make coveralls, lab coats, and fire hoods, and is now routinely worn by workers on process facilities at all times. It is also worn by workers who come in contact with energized electrical equipment.

One of the most widely used fire-resistant materials is sold under the trade name Nomex®. Pyrolon® is another commercially available FRC.

FRC should not be modified by adding decals or other decorations that could degrade the fire-resistant qualities of the fabric.

Normal clothing can be worn under the FRC. This clothing should be manufactured from natural materials such as cotton or wool rather than synthetics such as nylon or polyester.

The effectiveness of different types of FRC is determined using a thermal protection factor (TPP). The following guidance regarding TPP levels is provided:

- A factor of less than four is unacceptable for protection from flash fires.
- Four to six requires the wearing of a layer of clothing under FRC.
- Six or greater is optimum.

One company requires that FRC always be worn in the following situations:

- Whenever a piece of equipment or pipe that contains materials that could cause a flash fire is to be opened
- Emergency response in situations where hydrocarbons are likely to be present
- Maintenance, repair, or inspection of voltage systems (over 480 volts), as well as the installation of new electrical services of any voltage
- During fire training activities
- On offshore platforms

The need for fire-resistant clothing when carrying out electrical work is determined by NFPA 70E. It defines five hazard risk categories (HRCs) ranging from Category 0, that allows untreated 100% cotton, up to Category 4, that requires FRC.

IMPERVIOUS CLOTHING

Impervious clothing provides protection from splash and should be worn during jobs where it is possible to come in contact with highly acidic or corrosive materials. Such jobs may include the following:

- Breaking lines
- Opening equipment
- Jobs where liquid materials could splash or spray

Workers wearing impervious clothing are more likely to suffer from heat stress, a topic that is discussed in Chapter 7.

LABORATORY CLOTHING

The clothing requirements for laboratory work will depend on the materials being handled. (The material safety data sheets for those materials should provide guidance.)

Laboratory workers often handle hazardous chemicals directly; therefore, they will often be required to wear coats, goggles, and chemical-resistant gloves.

EMERGENCY PPE

Emergency responders need specialized PPE in order to fight fires and to enter areas that may be contaminated with toxic chemicals.

Firefighter protective clothing

Firefighter protective clothing, sometimes referred to as bunker gear, is worn by all members of fire teams and helideck fireguards. (Only those who are properly trained should wear this type of clothing.) Its use is required for those fighting fires beyond the incipient stage. It can be located either in a central location or on a fire truck.

The type of clothing will vary according to the local environment. However, the following should be the minimum requirements:

- Fire helmet with clear visor (safety helmets are not required).
- Fire coat and/or leggings. The coat should be of knee length and of Nomex III® or equivalent material.
- Insulated fire boots—at least calf height with nonslip sole tread and reinforced safety toe cap.
- Safety gloves.
- Self-contained breathing apparatus (SCBAs) for entering smoky areas.

Firefighter clothing should not restrict the person's movements. It should also be stored such that it cannot be contaminated or affected by heat, sunlight, or dampness.

Proximity suits

Heat-reflecting proximity suits are used by properly trained persons for taking actions such as closing a critical valve that is located close to a fire that has not yet been extinguished. On many offshore platforms, at least one person wearing a proximity suit will be on the helideck when helicopters are landing and taking off.

Fire entry suits are used for entering flame areas but only for precise snatch rescue work where the casualty location is known and not for firefighting under any circumstance.

RESPIRATORY PROTECTION

Although every attempt should be made to make sure that workers are never exposed to toxic or harmful vapors, there will be times when some form of respiratory protection is needed, if only as a precaution. This section discusses the types of protection that are available and how they can be used.

FIXED BREATHING AIR SYSTEMS

Respiratory protective equipment should be used in areas that do not have a safe breathing environment, or where there is the possibility of an unexpected release of toxic gas or particulates.

When respirators are used in atmospheres where the concentration of toxic gases could approach the immediately damaging to life and health (IDLH) level, standby personnel carrying SCBA should be present, along with suitable rescue equipment such as harnesses and hoists.

RESPIRATORS

The five most widely used types of respirator are as follows:

1. Air-purifying
2. Supplied air
3. SCBA
4. Chemical canister rebreathers
5. Disposable

Air-purifying respirators

Air-purifying respirators contain material that traps and purifies the air that the worker is breathing. They can trap either solid materials (particulates or dust) or toxic gases depending on the material used in the filter. Respirators of this type can be single or multiple use (replacement cartridges are put into the respirator for multiple use). In general, respirators in this category do not provide a high level of protection and should not be used when the concentration of toxic gas is close to IDLH (immediately dangerous to life or health).

Supplied air respirators

Supplied air respirators are connected via a hose to a supply of air. The air can come from a compressor or from cylinders. (If a compressor is used, it is essential that the air supply cannot become contaminated by fumes in the area.) Respirators of this type are safer than any type of system that purifies air because they do not rely on trapping or containing hazardous chemicals. Also, because they operate at positive pressure, a perfect fit is not imperative.

In some situations the person using the supplied air respirator will also wear a short-duration SCBA (see below) for emergency escape in the event that the flow of air is stopped.

Self-contained breathing apparatus (SCBA)

SCBAs are similar to supplied air respirators except that the air is supplied from a cylinder, usually carried by the worker. They are used for short-duration tasks, emergency rescue, escape, and process control procedures. The air supply is generally rated for 30 minutes, but this time is reduced if the work being performed is strenuous.

SCBAs should be inspected before each use; emergency units should be inspected at least monthly.

Chemical canister rebreathers

Chemical canister rebreathers are used only for emergency egress. The canister contains a special chemical that evolves as oxygen when contacted by the moisture and carbon dioxide in exhaled breath (the CO_2 and moisture are retained).

They are suitable for high concentrations of contaminants and oxygen-deficient atmospheres, but they are negative-pressure respirators that rely upon a perfect face-to-mask seal, which limits their use to emergency situations only.

Disposable respirators

These are intended for single use. They are primarily used for protection against nuisance dusts and nontoxic particles.

Use of respirators

Before using a respirator, the following checks should be carried out:

- The respirator should be checked for correct fitness before every use.
- Employees should not wear items such as facial hair or eyeglasses that could prevent a good seal. Employees who wear prescription glasses while working should be provided with specially designed units.
- All respirators should be inspected before each use to assure all parts are present and in good working order. There should be no cracks in the rubber or

lenses and head straps should be properly elastic. Hoses should be checked by being stretched and then looking for cracks.
- A check for leaks should be carried out by covering the mask with the palms of the hands and then inhaling gently. If the mask is pulled toward the face then the fit is good. The leak check is particularly important for negative-pressure respirators.
- The pressure in SCBA tanks should be as specified. The regulator pressure should be about the same as that of the cylinder. The low-pressure alarm should be checked.

HEAD PROTECTION

Hard hats/helmets protect the head from impact and penetration from falling or flying objects, overhead spills of hot or hazardous liquids, and electric shock. They should be worn at:

- Construction sites
- When near lifting operations or overhead work
- All process plant areas

Hard hats are made of rigid plastic, sometimes with a midline reinforcement ridge. Different styles are available (those made in the form of a traditional cowboy hat are often not permitted on process facilities).

Inside the helmet is a suspension that spreads the helmet's weight over the top of the head and that also provides a space of approximately 30 millimeter between the helmet's shell and the wearer's head so that if an object strikes the shell, the impact is less likely to be transmitted directly to the skull. The suspension generally has an adjustment knob or strap so that the hat can be used for different head sizes.

ANSI/ISEA Z89.1-2009—American National Standard for Industrial Head Protection—provides guidance regarding the selection of hard hats for different types of service. It classifies Type 1 for top protection and Type II for lateral impact protection. They also have three classes to do with electrical insulation rating. Class G (general) helmets are tested at 2200 volts; Class E (electrical) are tested to withstand 20,000 volts; Class C (conductive) provide no electrical protection.

ADDITIONAL EQUIPMENT/MARKERS

Hard hats can be fitted with additional equipment to improve comfort and safety. These include the following:

- A safety visor
- A brim to provide shade

- Built-in hearing protectors
- Reflective tape
- Mirrors
- A headlamp
- Heat-releasing vents
- A chinstrap
- Cold-weather insulation

It is a common practice to put stickers of company logos, training awards, and other emblems on hard hats. Workers may also put their names on the hat with permanent markers. It is necessary to ensure that the stickers and markers do not damage the integrity of the hard hat itself.

COLOR SCHEMES

Some companies assign color designations to hard hats. For example, the color red may indicate that the wearer is a member of the safety department. Or the color green may indicate that the person is a visitor (or a member of the safety department).

MAINTENANCE AND STORAGE

Hard hats do not require much maintenance. However, the following guidelines will help ensure their ongoing integrity:

1. Inspect regularly and replace at the first sign of cracking, dents, or other damage.
2. Store out of direct sunlight.
3. Use only mild soap solution to clean the hard hat and its suspension.

HAND PROTECTION

Gloves should be worn when hands are exposed to hazardous substances or to sharp, rough, or hot objects. The following types of glove are used:

- *Leather palm gloves* are often worn when carrying out heavy duty work. They resist heat, sparks, sharp, and rough objects, and provide some cushioning against blows, but they provide minimal protection from hydrocarbons and liquids.
- *Impervious gloves* are made of materials such as neoprene, PVC, or nitrile. They are used when handling hydrocarbons or corrosive chemicals such as acids and caustic.
- *Gauntlet-type gloves*, which extend above the cuff and protect the wrist and forearm, should be worn when there is a possibility of splashing.

- *Cotton gloves* protect against dirt and abrasion, but are not heavy enough for use with rough or sharp materials.
- *Latex gloves* provide for maximum dexterity but provide limited protection. They are used in light service, such as laboratory work and to keep oil, grease, and liquids off the skin.
- *Welders gloves* are made from treated leather that provides protection against heat, welding sparks, splatter, and hot slag.
- *Insulated gloves* are used in laboratories for handling distillation pots and other hot objects.
- *Electrician gloves* protect against electrical shock.

FOOT PROTECTION

Shoes used in process facilities should be notched or grooved to prevent slipping on oily or wet surfaces. They should also have a heel to assist with climbing ladders. Boots or shoes with steel toe caps should be used when a dropped object could crush a person's foot.

The following guidelines should be considered:

- Soles should be notched or grooved to prevent slipping on oily or wet surfaces.
- Boots or shoes should have oil-resistant soles and a heel.
- Rubber boots or overshoes can be worn to protect the feet and shoes from excessive water, oil, muck, or corrosive material.

Footwear of the following types should not be worn:

- Tennis and deck styles.
- Deep lug and hiking style soles.
- Crepe soles.
- Smooth leather soles.
- Western style or narrow throat boots.
- Lace-up and zipper style boot higher than 8 inches.
- Slip-on boot higher than 12 inches.

EYE PROTECTION

Eye protection should be used when there is a reasonable probability of eye injury. The requirements of OSHA's 29 CFR 1910.133 can be summarized as follows:

- Employers must ensure that each affected employee uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation.

- Employers must ensure that each affected employee uses eye protection that provides side protection when there is a hazard from flying objects. Detachable side protectors (e.g., clip-on or slide-on sideshields) meeting the pertinent requirements of this section are acceptable.
- Employers must ensure that each affected employee who wears prescription lenses while engaged in operations that involve eye hazards wears eye protection that incorporates the prescription in its design, or wears eye protection that can be worn over the prescription lenses without disturbing the proper position of the prescription lenses or the protective lenses.
- Employers must ensure that each affected employee uses equipment with filter lenses that have a shade number appropriate for the work being performed for protection from injurious light radiation.

SAFETY GLASSES

In general, safety glasses should be worn whenever a person is working outside at a process facility, working indoors with hazardous chemicals, and in most nonoffice work areas. Prescriptive lenses must comply with the overall safety glass policy. Safety glasses should meet the requirements of ANSI Z87.1, 2010.

CHEMICAL GOGGLES

Chemical goggles protect against splashing liquids, flying solids, and other harmful materials. Examples of work that may require chemical goggles are the following:

- Light chipping
- Dusty work
- Cutting wire
- Using grinders
- Handling mineral wool or fiberglass
- Handling hazardous liquids

CHAPTER

7 Health and industrial hygiene

CHAPTER OUTLINE

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INTRODUCTION

Although Health, Safety, and Environmental (HSE) activities are often grouped together and are often directed by a single manager, the three topics are actually quite distinct from one another. Table 7.1 gives who or what is covered by each of the elements of HSE and outlines the geographical scope and time line for each of those elements.

Table 7.1 Elements of HSE

Element	Covers	Time Line
Environmental/sustainability	All life forms	Years, possibly decades
Health	Public and workers	Months to years
Safety	Workers	Short term or instantaneous

Most of the discussion in this book is to do with safety and operational issues. However, it is also important to consider the impact of process work on the health of workers (the impact on people in the surrounding communities would generally fall under the environmental category).

Health issues generally affect only the workers at a facility and people living in the immediate neighborhood of that facility. The timeline for health concerns is likely to be considerably shorter than for environmental issues—typically weeks or months rather than years (although some poorly understood health issues may take longer than that to diagnose and understand).

Whereas environmental and safety compliance is typically driven by legislation, many health programs such as asbestos abatement are propelled by litigation, particularly in the United States. In other words, standards are developed through the use of law suits rather than government mandates.

An example of the distinction between safety and health can be seen in some offshore facilities. These facilities often use produced gas to drive turbines or in fired heaters. If the gas contains hydrogen sulfide (H_2S) then, when it is burned, the H_2S will be converted to sulfur dioxide (SO_2). The concentration of SO_2 in the exhaust plume will be very low because it is extensively diluted with the other gases such as nitrogen and carbon dioxide. Hence it does not pose a safety threat. However, over a long enough period of time, the SO_2 can have a health effect on those working on the platform.

Related to the topic of health is that of industrial hygiene, which is defined by the American Industrial Hygiene Association as follows:

> *[the] Science and art devoted to the anticipation, recognition, evaluation, prevention, and control of those environmental factors or stresses arising in or from the workplace which may cause sickness, impaired health and well being, or significant discomfort among workers or among citizens of the community.*

Health and industrial hygiene issues considered in this chapter include the following:

- Asbestos
- Noise
- Naturally occurring radioactive material (NORM)
- Food and galley hygiene
- Alcohol and drug policies

EMPLOYEE ACCESS TO RECORDS

Companies often collect a good deal of potentially sensitive information to do with the health of their employees and contract workers. Therefore, a policy should be developed regarding the rights of employees and contract workers regarding their access to that information.

For companies operating in the United States, OSHA's 29 CFR 1910.1020 provides the following guidance regarding the access rights of employees:

- Information as to the location of their health records and their exposure to toxic substances or harmful physical agents.
- Explanation of test results.
- Information should be stored and provided at no cost to the employee.

In practice, companies should develop a detailed policy based on guidelines such as these.

ASBESTOS

Asbestos comes in two forms: friable and nonfriable. Thermal insulation and wall plaster are examples of the former; flooring is an example of the latter. It is the friable form of asbestos that poses the greatest safety concern. It is defined as a material that contains more than 1% asbestos and that can be crumbled, pulverized, or reduced to powder by hand pressure. Its fibers can cause serious disease if inhaled. (The nonfriable form is often treated as friable because, once it is exposed, it can start to crumble.)

Although asbestos is no longer used in new installations, it occurs widely in older facilities and was commonly used for fireproofing (but has since been replaced with a range of cement-based products). Therefore, appropriate precautions have to be taken when maintaining or upgrading such facilities. The removal and disposal of asbestos should be managed by specially trained and equipped work crews. There are also many regulations to do with the material that must be followed. (In the United States, the topic is covered by 29 CFR 1926.1101.)

NOISE

Noise is airborne sound energy within a broad range of frequencies that has the potential to cause discomfort and/or hearing loss. The following are typical sources of high noise levels in the process industries:

- Fluid flow through pipes
- Sonic flow through control valves, steam let-down valves, and relief valves
- Fans, jets, and burners
- Vibrating machinery such as hoppers and extruders
- Grinders, mills, and conveyors
- Blades in turbines, fans, and blowers
- Electrical equipment such as motors and transformers
- High pressure let-down valves
- Flares

- Rotating equipment, particularly pumps and compressors
- Air intakes and vents, including burners and air-conditioning intakes
- Helicopters

Noise problems can be compounded by the fact that the noise waves can be reflected off walls and other surfaces, and may actually be amplified.

The noise generated by the equipment in a process facility must be controlled for the following reasons:

- Conserve the hearing of workers
- Allow for normal speech between workers
- Provide a quiet location for workers to relax (and sleep, if they are on 24 hours duty)
- Prevent annoyance to the local community

Discussion about noise will generally also cover the topic of vibration. Not only can vibration affect the health of workers in the same way as noise, but it can also cause equipment damage and failure.

REGULATIONS AND STANDARDS

The following regulations and standards apply to the management of noise in the workplace.

MSHA 30 CFR 62

This standard covers companies in the United States that are in the mining industry. Although broadly similar to the OSHA standard, some of the details differ.

OSHA 1926.101—Hearing protection

This standard provides limited guidance regarding the types of hearing protection that may be used.

OSHA 1910.95—Occupational noise exposure

For companies in the process industries operating in the United States, this OSHA standard is the one most commonly used. It provides values for the amount of noise to which a worker may be exposed.

NIOSH: Noise and hearing loss protection

At its website, the U.S. National Institute for Occupational Safety and Health (NIOSH) states:

> *Occupational hearing loss is the most common work-related illness in the United States. Approximately 22 million U.S. workers exposed to hazardous noise levels at work, and an additional 9 million exposed to ototoxic chemicals. An estimated $242 million is spent annually on worker's compensation for hearing loss disability.*

They offer a range of publications to do with the prevention of hearing loss, in particular their 92-page booklet, *Preventing Occupational Hearing Loss—A Practical Guide.*

EEMUA

The Engineering Equipment and Material Users' Association publishes various documents to do with noise control, including the following:

- EEMUA 140: *Noise Procedure Specification*
- EEMUA 161: *A Guide to the Selection and Assessment of Silencers and Acoustic Enclosures*

DEFINITIONS

The following definitions to do with noise are used.

Decibel

Named after the inventor Alexander Graham Bell, a decibel (dBA) is the unit used to express the intensity of sound. It is normally measured using the "A" scale, which approximates the human ear's response to a wide range of frequencies. A decibel is a logarithmic value to the base 10. Readings are given as dB(A) or dBA. Therefore, if the decibel value is increased by 10, the noise exposure has doubled.

A normal conversation takes place at about 60 decibels. A woodshop noise level is about 100 decibels, and a chainsaw noise measures about 110 decibels. Prolonged exposure to noise above 85 decibels can cause hearing loss.

Time-weighted average

The average level that is representative of employee exposure in the workplace in any 8-hour work shift of a 40-hour week.

Hertz

The hertz (Hz) is the unit of measurement for audio frequencies. The frequency range for human hearing lies between approximately 20 and 20,000 Hz. The sensitivity of the human ear drops off sharply below about 500 Hz and above 4,000 Hz.

Noise dose

The noise exposure expressed as a percentage of the allowable daily exposure. A 100% dose would equal an 8-hour exposure to a continuous 90 dBA noise; a 50% dose would equal an 8-hour exposure to an 85 dBA noise or a 4-hour exposure to a 90 dBA noise. If 85 dBA is the maximum permissible level, then an 8-hour exposure to a continuous 85 dBA noise would equal a 100% dose. If a 3 dB exchange rate is used in conjunction with an 85 dBA maximum permissible level, a 50% dose would equal a 2-hour exposure to 88 dBA or an 8-hour exposure to 82 dBA.

Threshold limit value

The level of acceptable noise can be set by federal, state, local, and corporate standards. Sometimes a threshold value for peak, intermittent levels is also needed. A value of 130 dBA is typical for this, depending on the frequency with which the noise occurs, and for how long it lasts.

NOISE LIMITS

The upper limit for allowable sound under any circumstances, including emergencies, is usually set at 115 dB(A). Some increase in the allowable noise level may be permitted for special operations. For example, sound levels of 115 dB(A) may be permitted for short periods of time during start-up, shutdown, regeneration, and maintenance. However, workers must wear hearing protection during such operations.

For normal operations, noise limits can be set at three levels:

1. Normal operations. The sound pressure level should not exceed 85 dB(A).
2. Special operating conditions such as start-up, shutdown, regeneration, and maintenance. In certain restricted areas, and under certain conditions, sound pressure levels above 85 dB(A)—but always below 115 dB(A)—are allowed. Equipment should be surrounded by an acoustic enclosure or else workers must wear hearing protection.
3. Emergencies. The sound pressure level should never exceed 115 dB(A) during emergencies.

Noise limits may be different for different times of day or night and for workdays or weekends, particularly if the facility is located in a built-up neighborhood.

The impact of high noise levels drops off quickly the further a person is from the noise source. Therefore, when making decisions about the control of noise, it is important to determine where the workers are likely to be located. One company states that a work area is any position in which a person may be present and which is no less than 1 meter from equipment surfaces, or any position where a worker's ear may be exposed to noise in the normal course of his duty. It includes platforms, walkways, and ladders.

Table 7.2 provides more detailed guidance as to allowable noise levels in different situations.

Table 7.3 provides values from OSHA 1910.195 for allowable time exposure. If these values are exceeded, feasible administrative or engineering controls must be provided. If such controls fail to reduce the sound to an acceptable level, personal protective equipment (PPE) is required.

The U.K. HSE states that a person must not be exposed to noise levels in excess of 85 dB(A) over an 8-hour period, or 88 dB(A) over a 12-hour period. Both these numbers are for a time-weighted average.

Table 7.2 Allowable Noise Levels dB(A)

Area	Maximum dB(A)
Areas in workshops and machinery buildings where communication is required	70
Workshops for light maintenance	
Workshops offices	60
Control rooms, not continuously manned	
Computer rooms	
Continuously manned control rooms	50
Open plan offices	
Social rooms, changing rooms, wash places, and toilets	
Offices, radio, and conference rooms	45
Accommodation	40

Table 7.3 Permissible Noise Exposures—OSHA 1910.195

Duration per Day (hours)	Sound Level, dB(A)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
≤0.25	115

Table 7.4 shows the maximum distances for spoken communication for different background noise levels and voice effort.

Continuous noise

For equipment that continuously makes noise, a maximum noise value of 85 dB(A) can be set. This limit applies to the overall equipment item, not to the components that make up that item.

Intermittent or fluctuating noise

Where equipment emits an intermittent or fluctuating noise such as when it is being depressured or blown down, noise limits such as those shown below can be applied:

- 8 hours: 85 dB(A)
- 4 hours: 88 dB(A)

Table 7.4 Face-to-Face Communication

Noise Level in Work Area (dBA)	Maximum Distance/Required Voice Effort (m)	
	Normal	Very Loud
55	10	35
61	5	18
69	2	7
75	1	4
81	0.5	2
87		1
93		0.5

- 2 hours: 91 dB(A)
- 1 hour: 94 dB(A)

NOISE CONTROL

There are five basic approaches to noise control based on the following principles of inherent safety:

1. Remove the source of the noise
2. Modify the source of the noise
3. Relocation/barriers
4. Enclose the equipment
5. Hearing protection

Remove the source

The best approach to noise control is to remove the source of noise altogether. If the process can be modified so that the equipment item that is generating the noise is not needed, then no further action is needed.

Modify the source

If the source of noise cannot be removed, then the next best step is to modify the source of the noise. Examples include the following:

- Control valves can be provided with an internal "drag trim" or "whisper trim" that limit the velocity of the fluid going through them.
- Special insulation or lagging can be installed on equipment, piping, and valves to muffle the noise that they generate.
- Motor noise can be reduced by using lower speed motors (1,800 rpm or less) or by using enclosures.
- Install silencers or mufflers on gas exhausts. There are two types. A reactive muffler contains baffles and chambers that block the transmission of sound. These are used for low-frequency noise source, such as that generated by

compressors. An absorptive muffler contains a porous material such as steel wool that absorbs the sound energy. It is important to ensure that silencers do not have internal parts that could break loose and that could block the silencer outlet or damage downstream equipment.

- The noise associated with rotating equipment can sometimes be reduced by controlling the level of vibration, often through the use of vibration isolators such as rubber pads.

Relocation/barriers

In some situations, it may be possible to relocate either the noisy equipment or the normal workplace of the technicians in the area. Also sound barriers can be installed; they block the path of the noise and reflect most of it back to the point of origin.

Enclose equipment

An enclosure is a prefabricated housing that absorbs the sound energy of the equipment. Its effectiveness is increased if acoustical absorbing material is added to its interior. A totally leak-tight enclosure may reduce exposure by 10—15 dB(A).

The use of acoustic enclosures is generally not a preferred solution to noise problems because they create a confined space and have the potential for a buildup of a flammable or explosive cloud should the equipment leak. Also, the containment structure is likely to make maintenance and inspection more difficult (a confined space entry will be required), and it will increase the size of the equipment's footprint.

Acoustic enclosures may be either of the "close fitting" or "walk-in" (large) type. Large enclosures should be subdivided in such a way that personnel servicing the equipment during partial shutdown are not exposed to excessive noise generated by other equipment that may also be in the enclosure. This can be achieved through the use of a separating wall between two independent trains of equipment.

Hearing protection

If engineering controls are not effective in reducing noise to an acceptable level, then hearing protection must be used. There are two basic types of hearing protection: ear plugs and ear muffs. Ear plugs are inserted into the ear canal and ear muffs cover the ears. Details to do with each are provided in the NIOSH publication referenced above.

A combination of ear plugs and ear muffs offers greater noise protection and may be appropriate for employees such as turbine mechanics who work at high-noise-level areas for long periods of time.

Administrative controls

Administrative controls, such the use of operating procedures, restricting access to high noise areas, and limiting the amount of time employees spend on high noise tasks or in high noise areas, are a last resort. Examples include signs and notices, barricades, procedures, and training.

VIBRATION CONTROL

Vibration control can be achieved in the following ways:

- Repair or modify the equipment that is causing the vibration
- Modify the equipment's mounting
- Put the equipment on steel or air springs
- Install isolation hangars for pipe that is connected to vibrating equipment

INDUSTRY ISSUES

If the equipment is onshore and the requirements of the local community need to be considered, then noise limits may be different for different times of day or night and for workdays or weekends, particularly if the facility is located in a built-up neighborhood.

Noise management on offshore platforms has the following three special features:

1. Environmental noise is not usually a concern. Most platforms are far enough from the shore that the noise that is generated will not affect the community, and general community noise will not affect the offshore workers.
2. At any given time up to half, the persons on board are resting or sleeping. They will generally require a lower level of ambient noise than those who are on duty.
3. The spacing between equipment is very restricted. It is hard for workers to get away from noisy locations. Hence noise management and control often plays an important role in the design of a facility—particularly with regard to layout.

NATURALLY OCCURRING RADIOACTIVE MATERIAL

NORM is found in many naturally occurring materials, including some oil and gas deposits. When NORM is transported to the surface in production streams it can precipitate and accumulate inside tubing strings, surface equipment, and piping as sulfate and carbonate deposits. NORM can also be found in refinery piping. It has been estimated that, every year, the U.S. oil and gas industry produces roughly 260,000 tonnes of NORM-contaminated sludge and scale, and around 18 billion barrels of contaminated waste fluid. NORM-contaminated materials typically contain uranium, thorium, lead, and radon, and their respective decay elements (their "progenys"). These materials present a risk to workers due to direct gamma radiation exposure and airborne radioactive dust inhalation.

The level of radioactivity can vary significantly, depending on the reservoir rock and the salinity of brine from the well. But in general, the higher the salinity, the higher the NORM levels. Also the standards for NORM, which were set 30−40 years ago (and updated since), may not provide sufficient information to understand how this material may affect workers.

NORM is a concern that is outside the normal purview of those working in the process industries—they rarely have to consider radioactive contamination and the appropriate protective measures. In an interview of Scott Hahn by Stancich (2011), he states, "One of the oil and gas sector's more dangerous oversights is that naturally occurring radioactive material (NORM) waste can be treated as a 'low level' radioactive waste stream. A growing body of evidence indicates that health and environmental impacts of NORM have been well underestimated, and that NORM waste streams are increasing at an unmanageable rate."

REGULATIONS AND STANDARDS

NORM is not federally regulated in the United States. However, some states, such as North Dakota, do have rules covering the handling of the material.

TENORM

Where the concentration of the radioactive materials has been increased during processing, the term Technologically Enhanced NORM (TENORM) is sometimes used. For example, during drilling, the produced fluids can contain radioactive materials such as Radium 226 and Radium 228. As these fluids approach the surface, changes in temperature and pressure cause barium and radium sulfates to precipitate out of solution and form scale on the inside, and sometimes on the outside, of the tubulars.

EXPOSURE

In general, personnel can work in the immediate vicinity of process equipment and piping containing accumulations of NORM without any significant increased health risk. However, the material may be a health hazard during maintenance when piping and equipment is opened and workers inhale or ingest NORM-contaminated scale, dust, or sludge. Therefore, before the work starts, these materials should be disposed of properly, preferably in plastic drums that are resistant to corrosion. If the contaminated dust cannot be removed, workers will need to wear respirators.

TREATMENT

Traditionally, final disposal methods for NORM waste have included spreading it on fields; leaving it in evaporation ponds (to leave a deadly legacy of contaminated soil and airborne radioactive particles); or discharging it into the nearshore marine environment (a method still widely practiced). More recently, companies began pumping the waste back down hole and sealing it in abandoned wells, or injecting it into salt caverns.

WATER/DRY BLASTING

In order to remove NORM, the current standard practice is to water blast, but this generates a considerable waste stream in itself, which is costly to store, and for which, in many regions, no appropriate final disposal option exists. An alternative is to use dry blasting which turns the issue of storing cubic meters of waste to liters of waste.

SAFE LIMITS

For nuclear energy workers, the allowable radiation "whole body" dose is 50 millisieverts a year. For nonnuclear energy workers, referred to as incidental workers (such as the third-party contractors), and members of the public, the maximum dose is 1 millisievert per year (1 mSv/year)—representing about 2−5 chest X-rays, depending on the individual and strength of the X-ray taken. These are "gamma" exposures from a source of radiation is "known" and therefore can be calculated. NORM radiation contains alpha and beta particles so there is no way of knowing just what the safe limits ought to be.

PROTECTIVE MEASURES

A worker exposed to NORM should wear appropriate PPE. The eyes, nose, ears, and mouth are mucus membranes and are possible entries into the internal structures of the human body and so should be protected in a NORM-contaminated environment. Cuts and abrasions are also a source of entry for particulate radiation.

LIFTING

A dated document—Applications Manual for the Revised NIOSH Lifting Equation (Waters 1994)—provides guidance as to the stress put on the human body in various lifting situations.

HEAT STRESS

The health of workers can be affected by thermal stress when ambient temperatures are too high. The stress can also be exacerbated by the type of work that is being carried out, *e.g.*, when someone is doing heavy physical work when ambient temperature is high. Other factors that affect heat and cold stress include humidity, wind speed, and the type of clothing that is being worn. PPE can also be a major factor in heat stress because it is often heavy, bulky, and not well ventilated.

HEAT INDEX

High humidity gives a perception of higher temperature. For example, if the actual temperature is 32°C (90°F), then the perceived temperature for various humidity levels are as shown below:

Humidity, %	Perceived Temperature (°C)
0	28
30	32
60	38
100	58

TYPES OF HEAT STRESS

Some of the types of heat stress are shown below. All actual cases of heat stress should be checked by a health professional:

- Heat stroke
- Heat exhaustion
- Dehydration
- Heat syncope (fainting)
- Heat cramps
- Heat rash (prickly heat)

All of the above can be serious, but it is heat stroke—also called sun stroke—that is of particular concern. It should be treated as a medical emergency. Although heat stroke usually follows from syncope and exhaustion, it can occur without any previous signs.

Heat stroke results from a failure of the body's temperature control system resulting in a core body temperature greater than 105°F or 40.6°C. In addition to fainting symptoms may include the following:

- Throbbing headache
- Dizziness and light-headedness
- Lack of sweating despite the heat

- Red, hot, and dry skin
- Muscle weakness or cramps
- Nausea and vomiting
- Rapid heartbeat, which may be either strong or weak
- Rapid, shallow breathing
- Behavioral changes such as confusion, disorientation, or staggering
- Seizures
- Unconsciousness

HEAT STRESS FACTORS

Many factors affect susceptibility to heat. Some of these factors are given in Table 7.5.

HEAT STRESS PREVENTION

General guidance to do with minimizing heat stress problems includes the following:

- Consume plenty of fluid
- Eat a good balanced diet
- Acclimatize
- Monitor him or her and coworkers
- Take breaks in cool areas
- Increase physical fitness
- Reduce caffeine intake
- Reduce nicotine intake

Table 7.5 Factors Affecting Heat Stress

Factor	Notes
Age	Older people tend to be more susceptible to heat stress.
Weight	Heavier people are more insulated and so have more trouble dissipating body heat.
Physical fitness	Increased fitness increases tolerance to heat stress.
Acclimatization	It can take 5 to 7 days to become acclimatized to high heat conditions. The acclimatization can be lost in just a few days.
Water intake	Workers in a high heat environment should drink plenty of water both before they start work and when they are performing the work.
Fatigue	Increased levels of fatigue contribute to heat stress.
Alcohol	Alcohol is prohibited from most work sites. One reason is that it increases the rate of dehydration and can flush needed electrolytes out of the body.
Caffeine/nicotine	Caffeine also leads to dehydration. Nicotine restricts circulation.
Medical conditions/ medication	Both prescription and nonprescription medications can reduce resistance to heat stress.

- Get medical conditions under control
- Schedule heavy work for the cool part of the day
- Increase staffing on heavy work jobs or jobs in hot areas
- Train workers to recognize the symptoms of heat stress, particularly heat stroke
- Provide portable fans
- Provide portable shade
- Provide cool vests/phase change vests
- Schedule project work so as to avoid outside activities during the summer months, particularly if PPE is to be worn
- Schedule daily work to be done at the coolest times in the day
- Establish a work/rest regimen
- Avoid heavy meals before and during work activities
- Set a program that requires workers to drink a specified amount of water at set intervals of time

COLD STRESS

When a worker is exposed to very low temperatures, the response of his or her body is to conserve body heat by reducing blood circulation through the skin. This effectively makes the skin an insulating layer. A second physiological response is shivering, which increases the rate of metabolism. Shivering is good sign that cold stress is significant and hypothermia may be present. However, these responses are relatively weak as a protection mechanism.

Cold stress should be controlled by providing workers with suitable clothing, active work, and moving them to warm locations as necessary. Generally better insulation is achieved by layering clothes rather than having one garment. A further advantage of layers is that a person can add or remove layers to adjust for differing insulation needs during the work period. The insulating value of clothing is greatly diminished by moisture. Sources of water are the work environment and sweat. Once the clothing is wet, it is extremely important to replace it immediately.

TYPES OF COLD STRESS

- Hypothermia
- Frostbite
- Frostnip
- Trench foot
- Chilblains
- Raynaud's disease

As with the discussion to do with types of heat stress, no detailed guidance is provided here as to the differences between these conditions. If someone could be suffering from one of these conditions, professional medical help should be called upon.

EQUIVALENT CHILL TEMPERATURE

The equivalent chill temperature or index shows the effect that wind speed has on perceived temperature.

The following is an example of how wind speed in km/hour affects perceived temperature when the temperature with no wind is −23°C.

Wind Speed	Perceived Temperature (°C)
0	−23
25	−43
65	−56

Temperatures above −32°C are not likely to cause frostbite if dry skin is exposed for an hour or less. Down to −56°C, there is increasing danger of freezing within a minute. Temperatures below that are of high danger—flesh can freeze within seconds.

CONTROLLING COLD STRESS

The following actions can reduce problems to do with cold stress:

- Set up a work−rest cycle
- Schedule work at warmest times
- Move work to warmer areas
- Assign additional workers
- Encourage self-pacing and extra breaks if required
- Establish a buddy system, emphasizing mutual observation
- Avoid long periods of sedentary effort
- Allow for productivity reductions and extra effort required when wearing protective clothing
- Provide an adjustment or conditioning period for new employees
- Monitor weight changes for dehydration
- Wear properly selected clothing
- Provide special attention to feet, fingers, toes, nose, ears, and face
- Wear gloves when the temperature is less than −9°C
- Use appropriate active warming systems such as circulation air or liquids or elective heaters
- Wear appropriate eye protection for snow or ice-covered terrain

RADIANT HEAT

Radiant heat from items such as flares, fired heaters, and exhaust pipes can be a source of ignition. Radiant heat can also injure people directly and can damage or destroy equipment.

Table 7.6 provides guidance as to representative values for the effects of radiant heat.

For most facilities, the most effective means of mitigating the effect of radiant heat is through the use of firewater, which can absorb around 9,000 BTU/gallon.

FOOD AND GALLEY HYGIENE

One of the most important aspects of industrial hygiene is to do with the preparation and serving of food, particularly on offshore facilities where workers are obliged to use the galley for all that they consume. Food can be contaminated by harmful microorganisms, toxic chemicals, poisonous plants, and animals. In order to avoid problems, the following issues should be considered:

- The appropriate design, operation, and sanitation procedures for a food service, including food production, transportation, storage, preparation, and serving.
- Methods for preventing and steps for investigating outbreaks of disease.
- This guideline for adequate levels of food-service sanitation offers information to avoid outbreaks of food poisoning or intestinal disease in all food-service facilities.
- Sources of exposure.

The health, personal hygiene, and work habits of food handlers are an extremely important part of protecting food from contamination. Hence even

Table 7.6 Radiant Heat Effects

Item	Intensity Btu/h/ft^2
Solar radiation on a hot summer day	320
Continuous exposure (no evacuation required)	500
Immediate evacuation from area required	1,500
Damage to exposed skin within 1 minute	1,760
Damage to exposed skin within a few seconds	3,000
Plastic melts	4,000
Plant equipment damage	7,000
Full storage tanks	10,000
Cotton clothing ignites within a few seconds	12,800
Spontaneous ignition of wood	20,000

those food-service employees exhibiting no visible signs of sickness may carry disease and should therefore have regular, semiannual, physical examinations. They should always be removed from food-preparation service if they are in obvious ill-health.

They must follow all rules to do with:

- Hand-washing
- Smoking
- The use of the toilet
- Hair restraints
- Sneezing and coughing
- Personal cleanliness
- The handling of tableware and cookware

METHODS OF PRESERVATION AND TREATMENT

The following methods of preservation should be considered with regard to the safe preparation and delivery of food:

- High temperature (e.g., pasteurization, blanching, and canning)
- Low temperature (e.g., refrigeration and freezing)
- Chemical preservatives (e.g., acids, antioxidants, salt, and sugar)
- Fermentation, smoking, dehydration, and radiation.

TREATING CONTAMINATION

The prevention of contamination includes the following measures:

- *Isolation.* Keeping all prepared, stored, or served food from harmful chemicals, insects and rodents, and contaminated water.
- *Substitution.* Where possible, mechanical processes should be used in place of manual operations.
- *Shielding.* Food on buffet tables should be protected through the use of shields and other separation devices that allow the customers to identify what they would like to eat but the serving is carried out by kitchen staff.

STORAGE AND COOKING TEMPERATURES

Foods should be stored below 7°C (45°F) and above 60°C (140°F) in order to avoid bacterial growth. Frozen foods should be thawed in one of the following ways:

- In refrigerators below 7°C (45°F)
- Under potable, running water at a temperature below 21°C (70°F)

- In a microwave oven following one of these procedures:
  - The complete, uninterrupted, cooking process occurs in the microwave oven.
  - The food is to be transferred immediately from the microwave oven to a conventional cooking unit where the cooking is completed without interruption.

Some foods, such as frozen vegetables and chops, should not be thawed but should be cooked directly after removing them from the freezer.

High-risk foods should be cooked so that all their parts are heated to at least 60°C (140°F) without any interruption in the cooking (with some exceptions).

FACILITIES AND EQUIPMENT

Food storage and service facilities should be built of easy-to-clean materials. Construction should ensure good seals at the ceiling and floor.

Equipment and utensils should be smooth, corrosion-resistant, made of nonabsorbent materials, and should be easy to clean. All food-contact equipment should be cleaned after use; grills and griddles should be cleaned at least daily.

The cleaning should ensure that equipment and utensils are immersed and sanitized for at least 30 minutes in clean, hot, potable water at least 77°C (170°F) or are immersed for at least 1 minute in a clean solution containing at least 50 ppm of available chlorine as a hypochlorite at a minimum temperature of 24°C (75°F).

An alternative is to rinse, spray, or swab equipment too large to immerse with a solution of 100 ppm available chlorine.

If a mechanical dishwasher is used, it is important to prescrape and rinse off food residues in a detergent solution of at least 71°C (160°F) for at least 40 seconds, with a final rinse of potable water at 82°C (180°F).

ALCOHOL AND DRUG POLICY

As part of their safety and health program most companies have a program to prevent employees and contract workers from using alcohol or drugs (both illegal and prescription) while at work. These programs will often provide free, anonymous treatment for those employees who request assistance. However, employees who fail a test, either one conducted at random or after an accident, are generally subject to strict disciplinary measures.

Customers, including government agencies, often have their own policies regarding substance and alcohol abuse that are incorporated into contracts. Covered personnel should generally cooperate with requests made under those policies.

Issues to consider when developing and administering an alcohol and drug policy are discussed below. (A full alcohol and drug policy will contain much more detail, particularly to do with the testing and disciplinary processes and what constitutes a restricted substance.)

COVERAGE

The policy should clearly define what facilities are covered, including those of affiliated companies and contractors. It should define the coverage for all owned or leased real and personal property, including marine vessels, aircraft, automobiles, trucks, equipment, and machinery. Generally the use of a personal vehicle while claiming reimbursement for mileage would be considered company business.

The policy should also specify the requirements of the pertinent laws and regulations.

AFFECTED PARTICIPANTS

The policy should clearly define who is covered. Generally all employees, both full-time and part-time, are required to participate. Contractors, visitors, and vendors may be covered by their own company programs. Each company employee will be given a copy of the company standard and will be expected to sign an agreement document such as that given in Table 7.7.

APPLICANTS FOR EMPLOYMENT

Subject to the relevant regulations, anyone applying for employment will be required to complete preemployment drug testing before being offered

Table 7.7 Acknowledgment Form

I have read the Company Alcohol, Drugs and Contraband Policy and the Alcohol and Drugs Standard. I understand their contents.

This policy and standard should supersede all other Company alcohol, drugs and contraband policies, standards or procedures.

I understand the Company may change this policy or standard at any time.

____

Print Name

____

Identification Number

____

Signature

____

Date

employment. If the applicant does not meet the test requirements, he or she may not apply for employment, including contract work, for a period of time such as 1 year.

TESTING

Drug and alcohol programs generally include a system of testing. The tests can be both scheduled and conducted at random. Generally the specimen collection for testing will be done at the work site during normal working hours.

Tests will also be conducted in the following circumstances:

- As required by law.
- Following a vehicle accident (including boats), regardless of whether there were any injuries.
- Following any reportable incident.
- Following any near-miss event that resulted in an incident investigation.
- If reasonable suspicion exists that an employee is under the influence of drugs or alcohol. Reasonable suspicion is based on direct observations and/or physical evidence of activities. Hearsay evidence is not a valid reason for testing.

Expenses for testing, including travel costs, should be paid by the company. All documents must be managed through a Chain of Custody procedure.

In all cases an appeal procedure must be in place.

CONTRACTORS

Companies generally require that all contractors have a drug and alcohol program and that each contractor employee be tested annually and before entering the company's premises. (Contractors or vendors whose need for site access poses a minimal safety risk may be exempted from preaccess substance abuse testing.) Contractor employees can also be tested upon reasonable suspicion by the contractor or company that an employee has consumed any prohibited substance.

The contract company will be required to remove any of their personnel from the work site whenever there is reasonable suspicion to do with the use of drugs or alcohol or following the occurrence of an incident.

CHAPTER

8 Human factors and ergonomics

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00008-1

INTRODUCTION

The operation and design of process plants involves input and participation from humans in every step of the way. Therefore, it is vital to understand how humans interface with equipment and instruments, how and why they make errors, and how systems can be designed to address human failings. The way in which this is done is through the topic of human factors, which has been defined as follows:

> *Human Factors is the discipline that integrates human capabilities, limitations, requirements and expectations in the design of products, workplaces and work systems.*

For the process industries, the incident at the Three Mile Island nuclear power plant in 1979 led to much better understanding of human factors issues. Many of the problems to do with that event were to do with the man–machine interface and with human performance. For example, one of the critical instruments on a control room panel display was covered with a piece of paper, and so was ignored. Also, those in charge of the response suffered from the problem of fixation: they chose to believe one instrument, even though it was giving wrong information and even though many other instruments were telling them to take different corrective actions.

The term ergonomics is used in Europe rather than human factors. In the United States, ergonomics is often treated as the discipline that focuses on musculoskeletal disorders and the comfort and long-term health of the workers. A common example of the application of ergonomics is the design of computer keyboards so that people do not suffer from wrist problems.

The term human factors engineering is the discipline to do with the design of systems so as to reduce human error and minimize ergonomics problems. It addresses engineering design rather than human behavior.

Regardless of the terms and labels that are used, the aim is always to optimize human efficiency, effectiveness, health, safety, and well-being, within the context of overall system performance operability, reliability, and maintainability.

PROCESS SAFETY MANAGEMENT

Because human factors are to do with the man–machine interface, it enters into almost all aspects of process safety management (PSM). Yet, in spite of its importance, human factors issues are not generally well integrated into most PSM programs or regulations. The topic rarely has a well-defined position within safety management systems in the way that say hazards analysis does.

This lack of clarity is illustrated by the following quotation from the General section of API RP 75:

> *Human factors may be considered in the design and implementation of the company's Safety and Environmental Management Program.*

The above statement provides no guidance as to the scope of a human factors analysis, when it is to be done, or how it links to the other elements of a risk management program:

Similarly the OSHA PSM standard, 29 CFR 1910.119, says only the following:

> *(3) The process hazard analysis shall address:*
>
> . . .
>
> *(vi) Human factors;*

No specific guidance is provided.

The safety and environmental management systems (SEMS) rule for offshore work in the United States says:

> *Human factors should be considered in the development of safe work practices. These safe work practices will normally apply to multiple locations and will normally be in written form (safety manual, safety standards, work rules, etc.).*

HUMAN ERROR

Most accidents and operating upsets involve some sort of human error. For example, Geyer et al. (1990) state that operator error is a direct cause of nearly a third of all pipework failures. (These errors consisted mostly of inadequately cleaning lines and incorrectly setting valves.) Indeed, it is almost certain that some type of human error will be involved in incidents because usually the operator being, in Trevor Kletz' phrase, "the last man on the bus" always has a chance to stop the chain of events. If he or she fails to do so, he or she is not to blame for the event—after all there were probably many other mistakes made by supervisors, managers, engineers, and designers prior to the final operator error. Looked at in this manner, all failures can be attributed to errors made by human beings somewhere in management chain.

If a piece of equipment fails to operate properly, then possible human causes include the following:

- The item was not properly specified by the design engineer
- The maintenance supervisor did not organize an effective inspection program
- A designer may have calculated loads and stresses incorrectly

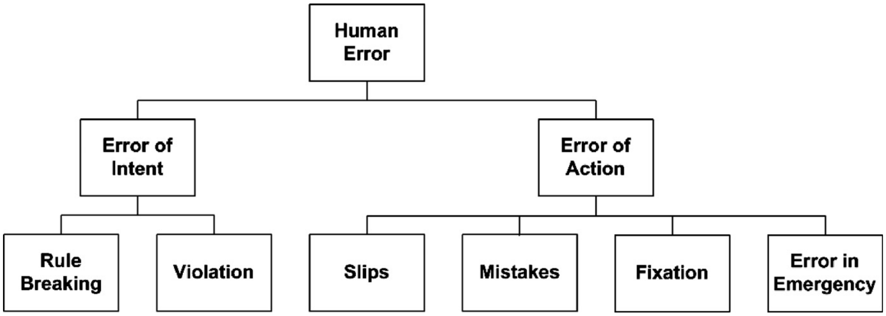

FIGURE 8.1

Human error.

- Management failed to implement a preventive maintenance program
- The operator may have failed to follow instructions.

Errors can either be of commission or omission. Errors of commission typically involve failure to follow procedures, taking a short cut or making an (incorrect) assumption about the validity of an instrument reading. Errors of omission often occur during the response phase of an incident. For example, an operator may fail to isolate a tank that has already started to overflow.

Human error can also be categorized as shown in Figure 8.1.

ERRORS OF INTENT

Sometimes people deliberately choose to do something that they know to be in error. Rule breaking is one example of this type of error, and, as discussed in Chapter 16, is very difficult to prevent or control.

Another type of intentional error is categorized in Figure 8.1 as a violation. Someone in authority deliberately decides not to follow a rule because, in his or her judgment, doing so will lead to safer or better operations. For example, an operations supervisor may choose to ignore a lab result or an instrument reading and not take the actions that those results would suggest he or she take, either because he or she does not believe the result or because he or she thinks that there is a better method of operation.

Temporary changes to equipment or instrumentation are often made quickly and thus bypass the management of change (MOC) system and thus are violations of the rules. In these cases, those involved decided that it was better to take corrective action quickly rather than work through the formal approval process. (However, once the conditions return to normal, the MOC process should still be implemented retroactively.)

An extreme example of how violation of the rules can help occurred on the Piper Alpha platform. The rules stated that, in an emergency, the men had to assemble in the living quarters. However, the quarters were filled with dense smoke—all those who assembled there eventually died. Some of those who decided not to follow the rules and move on to the deck were saved.

Sometimes design engineers have to decide whether to disobey their company's standards. On one facility, e.g., a new storage tank was being installed. The company standard called for the tank to have a fire monitor in each quadrant around it. But, in this case, the tank was near the facility's property line so it was not possible to put a monitor in that quadrant. In the end, the engineers decided to compromise the rule; they ensured that monitors had access to the tank in three of the quarters, and then put a fourth firefighting monitor in the structure that was adjacent and above the tank.

The point about violations is not that they are always wrong, but that managers and those in authority are able to exercise their judgment.

ERRORS OF ACTION

The next group of errors shown in Figure 8.1 is those where someone wants to do the right thing and tries to do the right thing, but gets it wrong. Errors in this category include slips, mistakes, fixation, and emergency response.

Slips

A slip occurs when a person makes an error, even though that person knew what to do and how to carry out a task. It is defined here as:

> *A slip is a human error resulting from failure to carry out an intention, even though the person concerned had the capability, time, and equipment to successfully carry out that intention.*

Slips usually occur during normal, routine, nonstress situations. For example, an operator may routinely take two samples from a certain section of the plant every shift, and he may have successfully performed this action hundreds of times. Then, on one occasion, he slips up and inadvertently switches the samples. Fatigue is a common reason for the occurrence of slips.

If it is found that workers are "slipping up" too often the work tasks need to be restructured. There is no point in requiring additional education or training; the point about slips is that people know what to do—they just do it wrong.

Mistakes

A mistake (sometimes referred to as a cognitive error) occurs when a person acts on an incorrect train of reasoning, often because he was not properly informed as to what to do or how to do it. A mistake can be defined as follows:

> *A mistake is a human error that is a failure in diagnosis, decision-making, or planning.*

Mistakes can be further divided into those that are "procedural" and those that are "creative." A procedural mistake occurs when, e.g., there is a lack of clarity in the operating instructions, thus causing an operator to misinterpret them. A creative mistake occurs when a brand-new situation develops, often during an emergency, and the operator has to develop a response on the spot, often in a very short period of time.

Mistakes imply thinking; slips imply routine.

A common type of mistake occurs when an operator or supervisor does not realize that he or she has exceeded a safe operating limit. Or he or she may realize that they are outside the safe range for operations, but decides to attempt to fight the problem rather than shut down and bring the facility operations to a safe state.

If workers are making mistakes, it may be appropriate to provide additional education (as distinct from training). Someone who is educated in a topic understands its fundamental principles, whereas someone who is merely trained in that topic knows "how to do it." The educated worker is more likely to analyze a situation correctly than one who does not understand the principles of the process that he or she is operating.

Fixation

Modern process plants are typically very complex and sophisticated. Therefore, when things go awry, it is often not at all obvious as to what may be causing the problems. In such situations, people have a tendency to reach a decision as to what is going on, and then not change their minds, even when new data tells them that their first conclusion was wrong. This is known as fixation.

Examples of fixation include the following:

- A plant experiences operating problems over a period of days. Different shifts witness different aspects of the problem, and so come up with different causes and proposed solutions. The people on each shift tend to discount the opinions of the other shifts because "seeing is believing"; people place more credence on their own experience than on the unwitnessed experience of others.
- During an emergency, an operator is typically swamped with a large amount of information from the control panel; much of the information is confusing or apparently self-contradictory, particularly if one or two instruments are in error. In such situations, most people tend to fixate on one or two instrument readings, and then exclude all other information, regardless of its relevance. (Fixation was an important part of the Three Mile Island nuclear power plant incident, where operations personnel chose to believe a faulty instrument, even though many other instruments were indicating that the signal from the first instrument was incorrect.)

Error in an emergency

A rule of thumb is that human error rates rise to 50% during an emergency, i.e., there is a 1 in 2 chance that a person will do the wrong thing during times of very high stress. Therefore, if an operator is called upon to perform, say, six tasks during an emergency, the chance of getting them all right is 0.5^6, which is 1.6%—in other words, he will almost certainly fail to implement the full sequence of tasks correctly. Consequently operators should not be expected to control a facility during an emergency. At most they should carry out a few automatic actions in which they have been thoroughly trained and then turn over control of the plant to the instrumentation and to the trained emergency response team.

THERP

Human error rates can be analyzed using a technique known as THERP (technique for human error rate prediction). The method uses Boolean logic to model and predict human error rates.

In effect, workers are treated as being components in a system, just like equipment items. Hence the THERP analysis can be integrated into probabilistic risk assessment (PRA) analyses—particularly fault and event trees—topics that are discussed in depth in *Process Risk and Reliability Management.* A THERP analysis is most effective when the tasks are routine and proceduralized, and when the persons involved are not under stress.

THERP can also be used for event tree modeling. For example, an initiating event could be an emergency situation such as a leak of a hazardous chemical. Items in the event tree that could incorporate human error include recognition that a leak has occurred, identifying the nature of the leak, and using the correct emergency response equipment.

When building a THERP model, errors are categorized and then assigned a probability. For example, an operator may be required to close a valve. Potential errors include the following:

1. Failing to close the valve
2. Closing the wrong valve
3. Partially closing the valve

If the likelihood for these errors is low, then they can simply be added together to obtain the overall error rate, corresponding to the OR gate in a fault tree. For example, if the respective likelihoods for the above errors are 0.01, 0.03, and 0.03, then the overall error rate is 0.07 (excluding second-order terms).

Broadly speaking, errors can be classified as either those of commission (doing something wrong) or omission (not doing something that should have been done). Errors of commission can then be divided into the following categories:

- Errors of selection—error in the use of controls or equipment
- Errors of sequence—required action is carried out in the wrong order
- Errors of timing—task is executed before or after when required
- Errors of quantity—inadequate amount or in excess

The error rates can be modified with a "recovery factor" which allows for corrective action to be taken before the consequences of the error affects the overall system performance (corresponding to the fault tree AND gate). For example, if there is a 40% chance that the operator will take immediate corrective action on closing the wrong valve, then the error rate for the second item in the above list falls to (0.03*(1.00 − 0.40)). In other words the likelihood of this error, given the potential for recovery, falls from 3% to 1.8%.

A database of human error probabilities (HEPs) is needed in order to develop the model. Three sources exist for the collection of data suitable for the generation of HEPs. They are as follows:

1. Data derived from relevant operating experience
2. Data derived from experimental research
3. Data derived from simulator studies

As with any fault tree approach, the results of the analysis are used to identify those activities which contribute the most to system failure (“the important few”) and to take corrective actions to reduce the overall failure rate.

Although THERP provides a useful way of integrating human error in probabilistic risk models, it does have two drawbacks. First, it is time-consuming and expensive to build a credible database of human error rates. And, related to this problem, the human beings are not equipment items that fail in some statistically measurable manner. The action of a human depends on many impossible-to-classify issues such as whether a person has just had a domestic dispute, or whether he or she is not feeling well that day.

ERGONOMICS

Ergonomics is the science of studying people at work and of their working environment. Ergonomics seeks to make a better match between workers’ physical capabilities and limitations and workplace conditions and activities. In practice, most ergonomics programs focus on preventing injury and illness by controlling or eliminating work-related musculoskeletal disorders (MSDs).

MUSCULOSKELETAL DISORDERS

MSDs are illnesses and injuries that affect one or more parts of the musculoskeletal system (bones, muscles, tendons, ligaments, joints, cartilage, peripheral nerves, and blood vessels). Injuries of this type account for a large percentage of recordable events. It is important that workers recognize the symptoms of incipient MSD problems and are able to obtain appropriate help.

Rostykus et al. (2013) identify five responses that companies take in response to injuries of this type. These responses are listed below. (In the spirit of risk management, as discussed in Chapter 1, before taking the actions listed below it is best to see if the activity or hazard associated with that activity can be removed altogether.)

1. Fix the person
2. Fit the person to the task

3. Change the person
4. Change how the person performs the work
5. Change the work or workplace

A brief discussion of each of these steps is provided below. In general it is best to start with the final step—change the work—first and to move up the list if necessary.

Fix the person

This approach is basically post-event, i.e., someone suffers an injury and is given medical treatment. It is the least desirable of the control options because it assumes that workers are going to be injured—it does not rely on prevention.

Fit the person to the task

Some people are not physically able to carry out certain tasks. For example, heavy weights should only be lifted by workers strong enough to do so. And it is common for people who have been injured to be put on light duties such as classroom training or filing government reports.

Change the person

Sometimes the persons performing a task can improve their capabilities. An example of this occurred at a medium-sized refinery. The operations manager noted that the organization spent many thousands of dollars on preventive maintenance and other reliability programs for their equipment, but did not invest at all in the fitness of their employees. So he installed a fitness work room at the refinery; it was open to all employees.

Change performance

A better approach to reducing problems with MSDs is to change how a person performs the work using behavioral modification (behavior-based safety is discussed in Chapter 4). Workers are trained in how to carry out tasks effectively and safely.

Change the work or workplace

Rather than trying to change people and their capabilities, it is best to change the manner in which a task is organized or structured such that the persons carrying out the work are exposed to a lower MSD risk.

WORK STATIONS

The topic of ergonomics is often associated with the design and use of work stations, including office computers and control panels. The following guidance to do with this topic should be considered:

- Equipment should be designed and adjusted to fit the workers' physiology.
- Documents that are being typed should be adjusted so as to be easy to read without the worker having to move his or her neck too often.

- Shiny paper that could cause dazzle should be avoided.
- Good visibility angles to the screen should be provided.
- The keyboard should be independent and mobile, thus allowing the worker to adjust it according to the tasks to be performed.
- The screen, the keyboard, and the support for documents should be positioned so that the eye—screen, eye—keyboard, and eye—document distances are approximately the same.
- Work surfaces should be adjustable.
- The maximum number of required touches of keys on the keyboard should not be over 8,000 per hour.
- A person should not work for more than 5 hours at a computer. Work conducted after that time period should not involve repetitive moves and visual effort.

HUMAN FACTORS ON PROJECTS

When a new facility is being designed, it is important to consider human factors issues as early as possible. Ideally potential problems can be removed so that there is no need to even consider behavioral issues.

The phase-gate approach to project management is described in *Process Risk and Reliability Management*. Human factors issues are generally addressed in the first three phases of a project.

PHASE I—CONCEPT SELECTION

A project is not likely to require much human factors input during the scoping phase. However, the human factors team can start on a preliminary task analysis to identify potential issues during the course of the project and to incorporate lessons learned from previous projects.

PHASE II—PRELIMINARY ENGINEERING

During Phase II, the human factors team will develop a plan covering topics such as the following:

- The human factors engineering deliverables
- The schedule for human factors work
- The human factors organization
- The role of human factors in the specification and purchase of vendor-supplied equipment

The overall layout of the facility will be decided upon during this phase. Therefore, human factors issues such as access to large valves should be incorporated into the discussions.

PHASE III—DETAILED ENGINEERING

During detailed design, detailed human factors engineering studies will be carried out as part of the overall program of hazard and risk analysis.

CONTROL ROOMS

A discussion as to developments in control room design is provided by Urso (2013). It considers the fact that current designs tend to create islands that tie operators to a particular console, and so limit communications with those working at other work stations. The article also notes that younger technicians are used to accessing information with smart devices and expect to see something similar in the work environment.

VALVE CRITICALITY ANALYSIS

The manual operation of large block valves has the potential to cause injury to the person carrying out the work. Also, if the operation of a valve is critical to safe operations, it is important to ensure that it can be operated quickly and reliably. For these reasons, it is important to conduct a valve analysis, ideally during the design of a facility. The steps in the analysis process are as follows:

1. List the manually operated block valves and also actuated valves that may have to be operated manually.
2. Determine the criticality of each valve.
3. Provide the appropriate level of accessibility for each valve.
4. Design the valves and valve handles.
5. The use of motor-operated actuators.

Typically, manually operated valves are organized into categories such as "operated daily," "operated occasionally," and "used only during turnarounds." The category selected will determine the location and accessibility of the valve—with those that are used daily being provided with easy access that does not require any stretching or the use of ladders or other temporary equipment.

The valve criticality analysis should be conducted by a team. During a project, the analysis will start once the P&IDs (piping and instrument diagrams) are available. Team members include the following:

- An operations representative
- A maintenance representative

- A project engineer
- A human factors specialist

The team will work through the process described above (listing the valves, determining their criticality, and deciding on accessibility of the valves). One company defines three levels of criticality as follows.

CATEGORY 1

Valves in this category possess the following features:

- They are used more than once every 6 months.
- They are essential to normal and emergency operations.
- They are essential to safe operations.
- Valves that fail frequently and that need to be repaired promptly.

Examples of valves in this category include vent and drain valves and routinely used block valves for filling and emptying vessels.

Permanent access should be provided for all Category 1 valves. Operation of a Category 1 valves should never require the need for stretching, twisting, reaching, or repetitive operation.

If the valve is large, difficult to operate, or must work quickly the use of an actuator should be considered.

CATEGORY 2

Valves in this category possess the following features:

- They are not critical for normal or emergency operations.
- They are used during routine maintenance activities but with a low frequency (less than once every 6 months).

Permanent access should be provided to these valves, but that access can be through the use of a small platform at the top of a vertical, fixed ladder. There should be sufficient space for the necessary personnel, tools, and parts.

Examples of valves in this category include bottom open drain valves that are used prior to maintenance, infrequently used manual isolation valves, and bypasses on isolation valves.

CATEGORY 3

Category 3 valves are used infrequently and are not critical to safe operations. Permanent access to these valves is not required; it is acceptable to use mobile platforms, lift cages, or scaffolding to gain access to them. (However, portable ladders should not be used.)

FIGURE 8.2

Fallen rock sign.

SIGNS

Signs are widely used throughout the process industries to advise people of hazardous conditions and to provide directions as to what actions to take in various situations. It should, however, be remembered that "Red Lights Don't Stop Cars—Brakes Stop Cars"; it is always best to engineer a solution to a hazard than to warn people about that hazard.

Training programs should include an explanation of the signs that are used by the company.

Where possible signs should be symbolic only, i.e., they should not contain wording. This policy reduces problems communicating with an international workforce. However, some signs that use symbols only can be confusing. For example, the "falling rock" sign shown in Figure 8.2 would appear to warn against rocks falling on vehicles. In fact, it is more to do with the fact that *fallen* rocks may be on the roadway.

If supplemental wording is necessary, then all the languages that are typically used at the site should be included.

REGULATIONS AND STANDARDS

The International Standard ISO 3864-1 provides guidance as to the selection and meaning of signs. Other standards that can be used include the following:

- ASTM F 1166-95a, Standard Practice for Human Engineering Design for Marine Systems, Equipment and Facilities, 1995.
- ABS Guidance Notes on the Application of Ergonomics to Marine Systems, January 1998.
- DOT/FAA/CT-96/1, Human Factors Design Guide for Acquisition of Commercial-Off-The-Shelf Subsystems, Non-Developmental, and Developmental Systems, January 15, 1996.
- Illuminating Engineering Society of North America. Recommended practice for marine lighting (IESNA RP-12-97), 1997.

- MIL-STD-1472F, Department of Defense Design Criteria Standard, Human Engineering, 23 August 1998.
- MIL-HDBK-759C, Department of Defense Handbook, Human Factors Engineering Design Guidelines, March 31, 1998.
- ANSI Z535 (similar to ISO 3864). It provides a safety sign color chart.

TYPES OF SIGN

Guidance as to the types of signs and their meanings is provided in the following sections.

Prohibition

Prohibition signs mean “You must not” or “Do not do. . .,” or “Stop.” Signs of this type have a red circle, a white interior, and a red bar, as illustrated in Figure 8.3. The sign can be supplemented with more specific information, as illustrated in Figure 8.4.

Other examples of prohibition signs include the following:

- No smoking
- No open flames
- Non-potable water

FIGURE 8.3

Prohibition sign.

FIGURE 8.4

Prohibition sign with information.

- Do not enter
- Do not fish
- Do not use crane for personnel transfer

Mandatory action

Mandatory signs mean "You must do..." or "Carry out this action," or simply "Obey." They are often used when special PPE (personal protective equipment) is required.

Signs of this type use a blue circle. Figure 8.5 shows that safety gloves are required.

Other examples of mandatory signs include the following:

- Hearing protection required
- Wash hands
- Chock wheels
- Ground fuel truck
- Hard hat area
- Doors must be kept closed
- Goggles required
- Face shield required

Warning

Warning signs are yellow triangles using black lettering, as illustrated in Figure 8.6, which is to do with electrical hazards.

Other examples of warning signs include:

- H_2S gas
- Corrosive liquids
- Radiation
- Equipment automatic start
- Open trenches
- High temperature
- Flammables

FIGURE 8.5

Mandatory sign.

FIGURE 8.6

Warning sign.

FIGURE 8.7

Escape sign.

- Explosives
- Danger high voltage

Safe condition

A green square or rectangle indicates a safe condition, a means of escape or the location of safety equipment, as illustrated in Figure 8.7.

Other examples of safe condition signs include:

- Emergency shower station
- Emergency eyewash station
- Potable water
- Emergency shutdown
- First aid
- Trash

Fire safety

A red square or rectangle is to do with fire safety, as shown in Figure 8.8.

FIGURE 8.8

Fire sign.

LABELING

The following guidance should be considered when labeling equipment and piping systems:

- Valves should be labeled as to their purpose and function, particularly when two or more similar-looking valves are in the same location.
- Labels should be located as follows:
  - Close to isolation valves
  - Adjacent to changes in direction
  - Branches
  - Where the pipe disappears from view (say going underground or through a wall or deck)
  - Boundary units
- Labeling should be large enough so as to be readable from a normal working position

COLOR CODING

The use of a color coding system allows workers to quickly identify which systems are hazardous. The following color coding standard is frequently used.

- *Red* for the identification of:
  - Fire protection equipment and apparatus, including fire alarm boxes, fire blanket boxes, fire extinguishers, fire exit signs, fire hose locations, fire hydrants, and fire pumps.
  - Safety cans or other portable containers of flammable liquids, lights at barricades and at temporary obstructions, and danger signs.
  - Stop buttons and emergency stop bars on hazardous machines.
- *Orange* for the identification of dangerous parts of machines of energized equipment.
- *Yellow* for designating caution and marking physical hazards such as falling, stumbling, tripping, striking against, and "caught in between."
- *Green and/or white* for designating safety and the location of first aid equipment.

- *Blue* for designating caution—typically warning against starting, use of, or movement of equipment under repair or being worked upon. Blue is used on information signs and bulletin boards that are not to do with safety.
- *Black on yellow* for radiation: X-ray, alpha, beta, gamma, neutron, and proton radiation.
- *Black, white, and combinations of black and white* for housekeeping and traffic markings. Black and white can also signify boundaries of traffic aisles, stairways (risers, direction, and border limit lines), and directional signs.

EXPOSED PIPING

Where possible, piping should be color coded, often using color bands. The following system is representative:

- Red background, white legend: Fire suppression systems.
- Green background, white legend: Utility, instrument, or breathing air.
- Blue background, white legend: Potable and nonpotable water.
- Yellow background, black legend: Natural gas, corrosives, and hazardous materials.
- Aluminum background, black legend: Liquid hydrocarbon piping—including crude oil, diesel, jet fuel, liquefied petroleum gas, naphtha, gasoline, and lubricants.

The color coding can be supplemented with labels that show the pipe contents, the flow direction, and to/from information.

HOSES

A representative coding system for hoses is as follows:

- Red—flammable gases
- Green—oxygen
- Black—breathing air
- Blue—inert gases

Another system that is used for bulk hoses is as follows:

- Blue spiral stripe—potable water
- Brown spiral stripe—diesel
- Yellow longitudinal stripe—base oil
- Orange longitudinal stripe—oil-based mud
- Red spiral stripe—brine mud/brine
- Green spiral stripe—cement
- Orange spiral stripe—bentonite or barite

CHAPTER

9 Firefighting

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00009-3

INTRODUCTION

Most process facilities, either onshore or offshore, handle large quantities of highly flammable gases and liquids. And, in spite of the most careful precautions, there are times when large quantities of these materials are released. They can then find a source of ignition resulting in a fire. Hence it is important that all process facilities are provided with firefighting equipment and services, and that the workers at those facilities know how to respond when the worst happens.

Firefighting is just one part of the overall topic of emergency management, the principles of which are discussed in *Process Risk and Reliability Management*. The Table of Contents for that chapter is given in Table 9.1.

With regard to firefighting specifically, the basic philosophy for the operators and technicians to follow is:

1. If possible, isolate the fuel source.
2. Cool the area around the fire if water is available.
3. Extinguish incipient or starting fires when possible.

Training is a crucial aspect of firefighting. In particular, operating technicians must not only know what to do if a fire starts, they must also know when it is out of control and the emergency systems need to be activated.

REGULATIONS AND STANDARDS

There are many standards to do with firefighting and with emergency response in general. Those listed below are representative:

- Occupational Safety and Health Administration, Department of Labor; 29 CFR, 1910.156, 1910.157
- 1910.164, 1910.179, 1910.106
- National Fire Protection Agency—NFPA 10
- National Fire Protection Agency—NFPA 13
- National Fire Protection Agency—NFPA 30

Table 9.1 Emergency Management

- Introduction
- Abnormal Situation Management
- Human Response
    - Human Error Rate
    - Fixation
    - Heroism and Buddy Loyalty
- Troubleshooting
- Levels of Emergency
- Cause of Emergency
- Emergency Operations
- Local Emergency Response
- General Emergency Response
- Recovery Operations
- Investigation and Follow-Up
- Emergency Planning
    - Organization and Personnel
    - Emergency Response Manual
    - Emergency Procedures
    - Emergency Response Training
    - Communications
- Emergency Shutdown
    - ESD Hierarchy
    - Shutdown Zones
    - System Reset
- Fire and Gas Detection
    - Fire Detection
    - Fire Eyes/Flame Detectors
    - Smoke Detectors
    - Heat Detectors
    - Fusible Links
    - Low Oxygen Detectors
    - Combustible Gas Detectors
    - Manual Call Points
    - Toxic Gas Releases
- Escape Routes
- Firefighting
    - Single-Fire Concept
    - Deluge Systems
    - Fire Zones

PRINCIPLES OF FIREFIGHTING

In Chapter 1 it was noted that risk can be divided into four components: hazard, consequence, likelihood, and safeguards. It was also noted that it is generally best to reduce risk in that order, i.e., to start by removing hazards and only to rely on safeguards if no other action can be taken. Therefore, with regard to firefighting, it is suggested that the following sequence of actions should be followed wherever possible.

REMOVE THE FUEL SOURCE

The most effective way to extinguish a hydrocarbon fire is to stop feeding fuel to it. This is often done with Emergency Isolation Valves (EIVs) that are located at the perimeter of the facility. These valves either stop the flow of fuel to the fire or they direct the inventory of hydrocarbon to a safe location, as with emergency depressuring valves. The valves must be able to withstand the largest plausible fire radiation (this is often done by placing the valves behind an earthern wall or bund). If operators need to reach these valves during an emergency they should be provided with protected access and egress routes.

Local fires are also best extinguished by stopping the flow of fuel. For example, if a pump seal leaks and catches fire, the best response is to close the suction and discharge valves on either side of the pump. If the pump is in critical service or at a critical location, the valves should be capable of remote operation.

Probably the best, and most tragic, example of *not* stopping the flow of fuel to a fire occurred at the *Piper Alpha* platform in the North Sea in the year 1988. It is thought that seven men died in the initial explosion. Yet the final death toll was 167. This is surprising given that the inventory of oil and gas on a platform such as *Piper* is low—a fire should burn itself out in less than 15 minutes. Yet the fire continued to burn for hours—the reason being that adjacent platforms, which were feeding hydrocarbons to *Piper* (which was a hub platform)—did not stop feeding the raging fire because "no one told them to stop."

CONSEQUENCE AND LIKELIHOOD

If the flow of fuel to a fire cannot be stopped, priority should be given to controlling the consequences of that fire. For example, firewater can be used to keep equipment and tanks in the area cool. This action does not stop the fire itself, but it does limit the overall damage.

The likelihood term is not relevant to emergency response since the fire has already started.

SAFEGUARDS

The last line of defense in firefighting response is the use of safeguards such as emergency response systems and specialized personal protective equipment (PPE) for the members of the emergency response team.

SINGLE-FIRE CONCEPT

The firewater system and the firefighting equipment are generally designed to handle just one major fire at a time. In other words, the design capacity of major firefighting facilities is determined by the largest single-fire contingency (this is analogous to the single event scenario concept used in relief valve design). Some firefighting systems are sized to handle less than worst case situations. For instance, foam concentrate requirements are usually determined by a tank fire rather than by the worst contingency, which may be a fire in the process area.

FIRE ZONES

For all but the smallest facilities fire zones are used. They ensure that firefighting systems are used only in those areas that actually have a problem. Offshore platforms, e.g., are typically divided into about seven zones.

Figure 9.1 shows the use of fire zones. A ring main goes around the entire facility. It is filled with water whose pressure is maintained with a jockey pump. Connected to the ring main are multiple zones. The firewater headers in each zone are normally dry. In this example, there are two firewater pumps, each of which has sufficient capacity on its own to handle the design fire case. These pumps are placed in different locations at the facility so that, if one is destroyed, the other will provide a full flow of firewater. It is common for them to have different power supplies—in particular, one of them will be driven by a stand-alone diesel motor that operates independently of the facility's utility systems.

If a fire occurs in one of the zones, a fusible link will fail, causing the pressure control deluge valve (PCDV) to open and the main firewater pumps to start. Water will flow out of the sprinkler heads in that zone only. The PCDV can also be tripped manually.

Once the fire has been brought under control, the system is reset. If seawater is used as deluge water, then it is important to flush the zone headers and deluge nozzles with freshwater, otherwise corrosion products will build up.

FIREWATER

Water is the most widely used fire extinguishing material because it is both economical and effective. Offshore, seawater is always available (although equipment

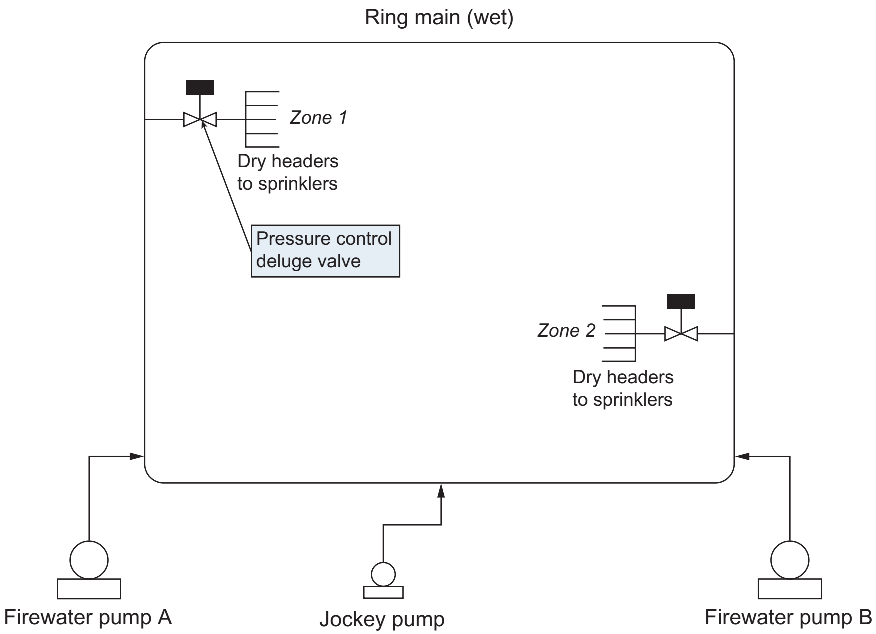

FIGURE 9.1

Fire protection system.

has to be flushed with freshwater once the emergency is over). Onshore, firewater can be obtained from nearby rivers or dedicated firewater ponds.

Water has excellent quenching capabilities, cooling effectiveness, and, for some materials, vapor dispersion characteristics. Its high latent heat means that it absorbs a lot of heat when it is converted into steam by the fire. Moreover, the steam generated as fire vaporizes water can displace or exclude air, extinguishing a fire by smothering.

When delivered in the form of a light spray, water cools the surface of hot oils, potentially bringing them below their flash point. Water on viscous oils can form a froth that puts out the fire. A water spray reduces the size and intensity of the flame, and cools and protects materials exposed to flames.

Water can also be used as a smothering agent, particularly in fighting fires involving liquids that are denser than water (e.g., carbon disulfide). Flammable materials that are soluble in water (e.g., methyl alcohol) may, in some instances, be extinguished by dilution.

Whatever the source of water, good drainage is required. The drained firewater may be contaminated with various chemicals, so it must be sent to a location where it can be treated before being discharged to the environment.

WATER CAPACITY AND RATES

As already discussed, the requirements of the largest single-fire determine the capacity of the firefighting facilities. In practice, this means that the design is based on the assumption that only a single unit will be involved. Where separation of units or hazardous equipment is less than 15 meters, the combined area is considered to be a single-fire area.

Table 9.2 provides rough guidance for the required firewater capacity in different services. The figures will need to be adjusted to meet specific circumstances, regulations, industry standards, and corporate guidelines. Also, the rate and duration of water flow for each plant or facility will depend on the amount of hydrocarbon liquid contained in the area and the capability to stop flow of fuel to the area quickly.

DELUGE SYSTEMS

Deluge systems are used to extinguish fires, and to dissolve, disperse, or cool flammable liquids and gases so as to minimize gas expansion and/or liquid boil off. Deluge water also cools structures to prevent deformation or collapse due to heat and can help additional leakage from flanges or connections, as well as a vessel rupture. In general, nonfireproofed vessels with liquid holdup of 3,500 liters or more should be provided with water cooling. Remote locations where a fire does not pose a significant risk to people or equipment may be an exception.

SOURCES OF FIREWATER

Most water that does not contain a significant amount of hydrocarbons is suitable for fighting fires. Firewater sources include seawater, ponds, rivers, and reservoirs.

High-value facilities should have two independent supplies of firewater. Backup water can come from a variety of sources including wells, ponds, canals, rivers, lakes, cooling tower basins, cooling water storage tanks, and boiler feedwater storage. (If cooling water is used, it is important to confirm that doing so will not deprive vital equipment of needed cooling and that the water treatment chemicals do not cause any problems.)

Municipal water systems can be a suitable source of water for fire protection. However, because they are usually at low pressure, a booster pump will probably be needed. Also, it is important to ensure that backflow prevention devices are installed—hydrocarbons or toxic chemicals must not be allowed to flow back into the municipal water system.

If a public water supply is used, it is important to ensure that:

- There is an alternate power supply for electrically driven pumps
- The supply is capable of meeting the largest instantaneous demand

Table 9.2 Water Capacity Guidelines

Facility	Duration (hour)	Capacity (gpm)	Capacity (m^3/h)
Offices, warehouses, workshops, and single berth docks	1	500–1,000	120–250
Small processing units, operating units with low hydrocarbon content, tank farms, and pipeline terminals	2	1,000–2,000	250–500
Midsize processing units, gas plants, multiberth docks, and offshore platforms	4	2,000–4,000	500–1,000
Integrated, high-value plants	4	4,000–6,000	1,000–1,500
Integrated, high-value plants with large quantities of fuel above 70 barg	6	6,000–8,000	1,500–2,000

- The supply is not subject to a single impairment or valve closing
- There is no history of system failure
- The primary pumping station is not subject to flooding

Wells cannot be used as a source of firewater but they can be used to refill a tank or pond.

If firewater is supplied by tanks, then a proper level of water should always be maintained in the tank, which should also have a low-level alarm.

TESTING

The firewater distribution system should be pressure tested regularly (at least weekly). The following are representative test parameters:

- Test to 3 bars above the maximum pump discharge pressure.
- The actual flowing pressure at various discharge rates at representative locations should be measured. The performance curves can be compared to previous flow tests to detect signs of obstruction or restriction.
- Water should be flushed out of dead ends and hydrants on a regular basis.
- Pumps should operate long enough to ensure complete warm-up.
- The firewater system should be flushed regularly.
- Each section of fire hose shall be hydrostatically tested annually at maximum pump pressure for at least 3 minutes.

FIREWATER PUMPS AND DRIVERS

Virtually all facilities need pumps to ensure that the firewater is supplied at sufficient pressure. These pumps must be highly reliable and spared where possible. The pumps should also be in different locations, as illustrated in Figure 9.1, so that a single fire does not knock both of them out of action. If one pump stops working, the other must automatically start.

Jockey pumps

A jockey pump maintains pressure on the firewater system at all times. The set pressure will typically be in the range 8—10 barg. Generally, the jockey pump will turn itself on and off depending on the header pressure. If the pump runs continuously its discharge should recirculate through a minimum flow bypass.

Systems without jockey pumps need to have surge protection to avoid damaging the piping when the main pumps start.

Main fire pumps

Main fire pumps should be automatically controlled to start whenever there is a demand that reduces system pressure below a set point of say 7 barg. They should be large enough to keep the pressure above that set point at the most distant hydrant and at the system design flow rate. Spare pumps should be diesel engine driven with independent fuel tanks. Where steam is available, steam-driven pumps may be used to supplement the electric- and diesel-driven units.

Pumps on fire trucks can pump water as soon as the truck reaches the fire. The pumps may be front-mounted and engine-driven by an extension to the engine crankshaft, or mounted behind the cab and driven through the main truck transmission. Occasionally pumping units have their own separate engine drive.

FIXED WATER SPRAY SYSTEMS

Firewater is used not only in direct firefighting but also, as a spray, to keep vessels and structures cool so that they do not rupture or fail. Water in spray form is more effective than straight streams, especially on burning surfaces and on surfaces to be cooled. (Water sprays are not effective in providing cooling for high-velocity, jet-impinging fires. The velocity of jetting gases blows the water spray droplets away from the vessel shell.)

In most situations, water spray streams can be applied with hand-directed nozzles on hoses or monitors after a fire starts. However, fixed sprays can be considered as protection for the following types of equipment:

- Process vessels containing 10,000 liters or more of flammable liquid under pressure, and where monitor streams cannot reach all exposed surfaces above the normal liquid level (sprays on vessels should be applied to the top of the vessel because the surfaces of the lower half are not always wetted by water rundown from above).
- Mechanical equipment containing liquids above their auto ignition temperature or that are volatile and located under other high-value equipment.
- Where pumps are handling hydrocarbons above 300°C or above their auto-ignition temperature.

- Where high-value, critical pumps are located under other high-value equipment, such as air coolers.
- Where critical equipment is located on offshore production platforms, such as wellhead production and compression equipment areas.
- Where critical equipment resides in unattended facilities or where firefighting personnel may not be immediately available.
- Where sprays are used as an alternative to fireproofing for structural members or critical instrument cables.

AUTOMATIC SPRINKLER SYSTEMS

Sprinkler systems are used in offices, laboratories, warehouses, and offshore living quarters. When used offshore, sprinkler systems are normally packed with freshwater to minimize corrosion problems. Saltwater replaces the freshwater during the course of the emergency.

MONITORS/HOSE CARTS

Fixed monitors, which can be either fixed or portable, provide fire coverage for specific equipment items or structures within a facility. Two fixed monitors may be required, one on each side of the equipment item, to adequately protect a single risk in adverse wind conditions. Monitors discharge large volumes of water and have good straight stream range. Discharge can be controlled by the type and size of adjustable nozzle or diameter of straight stream nozzle.

Portable monitors, which come in a wide range of sizes, should be strategically located around the facility. During a fire, they can be quickly moved and connected by hose to the nearest hydrant. Due to the wide variation in flow rates and ranges that can be obtained from monitors, each installation must be designed for the specific risks and conditions involved.

Monitor nozzles are not the primary water flow shutoff. The block valve at the monitor must be closed when the monitor is not in use. To reduce friction loss and to prevent damage to valve parts, the block valve should always be opened wide when in use.

Hose carts shall be equipped with wrenches, nozzles, and small equipment as necessary.

FIREWATER DISTRIBUTION SYSTEM

When installing a firewater system, consideration should be given to the materials of construction and to the overall layout.

Materials of construction

Steel pipe should be used aboveground for firewater lines. Underground piping systems can be constructed of steel, cement-lined steel, or high-density polyethylene (HDPE). Concrete is sometimes used but is seldom economical except in large diameters. HDPE does not corrode, resists accumulation of scale, and is very ductile and lightweight. Because it fails when heated, HDPE pipe can only be used in buried installations. Burial also provides protection from mechanical damage.

Layout

The topic of equipment and piping layout is discussed in Chapter 11. Issues to do with the layout of a firewater system are described below.

In climates where freezing does not occur, above-ground installation of steel firewater distribution lines has the advantages of low first cost and ease of inspection and repair. In cold climates, distribution lines should be buried below the frost line.

When possible, firewater mains should be arranged in loops around process facility and tank farms. Shutoff valves should be located to allow isolation of system segments for maintenance while still providing water for all facilities. The minimum water rate with a section of pipe out of service should be at least 60% of the design rate at design pressure for that area. A firewater header should be provided in each process facility area to serve hose stations.

Deluge valves

High-performance butterfly valves and gate valves are recommended for block valves in firewater distribution systems. They should provide reasonably tight shutoff and use sealing materials that do not swell or deteriorate with age. Any valve that may be buried, and that may therefore not receive frequent maintenance should be very durable.

The operation of the deluge valves will be initiated automatically by the fusible plug fire detection systems, through direct action and through instrumentation. Zone valves should be able to be opened manually.

Hydrants

Hydrants should be located close to the buildings and structures that they are to protect, while being far enough away that operators and emergency responders can use them safely. Unless booster pumps are used, hydrants should not generally be more than 150 meters from one another.

OTHER FIREFIGHTING MEDIA

Although water is generally the preferred medium for firefighting, other materials can be used. Some of them are discussed below.

Halon

Halons are vaporizing liquids that chemically inhibit combustion by interrupting flame propagation in the same manner as a dry chemical. They are very effective, but they also damage the ozone layer in the atmosphere. Therefore, their production and use is no longer permitted.

Steam

Steam is not normally used for fire control. Unlike water, steam is not effective in cooling or protecting fire-exposed equipment to prevent further damage. However, because of its availability in most process plants, it provides an economical way to prevent some types of small fires. It is especially useful in preventing ignition of leaks in hot equipment such as furnace header boxes, where the leak is not serious but can be stopped only with a shutdown. It is also effective in preventing ignition of flange leaks by reducing the amount of air available at the leak and by dispersing and diluting the leaking material.

Handheld, unbonded steam lances not in contact with piping can ignite leaks when static electricity accumulates on the lance and is subsequently discharged.

Foam systems

Foam is a blanketing agent consisting of an aggregate of gas-filled or air-filled bubbles that can float on an oil surface. It prevents its contact with air, cools the surface, and inhibits (or suppresses) the formation of flammable vapors. It is used primarily for extinguishing liquid pool fires. It is expensive to purchase and to store.

Foam is effective on any liquid hydrocarbon at temperatures up to the boiling point of water. Applying foam to hydrocarbons heated above the boiling point of water may cause frothing. Foam, being largely water, is also an effective quenching agent for fires in ordinary combustible materials.

Carbon dioxide

Carbon dioxide (CO_2) extinguishes almost entirely by smothering, although it does have a slight cooling effect. It is clean and leaves no residue that can damage electrical and electronic equipment.

Liquid CO_2 is stored under pressure in steel cylinders. When the valve on the cylinder opens, the rapid expansion of the liquid into gas produces a refrigerating effect, which solidifies part of the carbon CO_2 a “snow.” This “snow” soon sublimes into gas, absorbing heat from the burning material or surrounding atmosphere. The gas extinguishes fire by reducing the oxygen content of surrounding air below the flammable limit of the fuel.

Unless this concentration of gas is maintained for an extended period, CO_2 does not normally extinguish fires in materials that smolder or produce glowing embers, such as paper and wood. Its greatest effectiveness is on flammable liquid fires that do not involve material that might reignite after the CO_2 has dissipated. It is especially suitable for use in laboratories and in the protection of electrical and electronic equipment.

CO_2 flood systems are acceptable only in small unmanned buildings or equipment enclosures (e.g., combustion gas turbine enclosures) because they reduce the levels of oxygen in air to unacceptably low concentrations. Once the system has been activated, entry into the area is prohibited unless self-contained breathing apparatus is worn.

Earth-moving equipment

Earth-moving equipment such as front-end loaders, backhoes, and bulldozers can be useful for controlling fires involving tanks and oil wells. They can create diversionary or impounding walls and can remove debris.

The engines of most heavy equipment are a potential ignition source, so the use of such equipment when flammable vapors may be present should be carefully controlled.

UNDERGROUND FIREWATER SYSTEMS

An underground firewater system is any part of a firewater system that is underground, including storage, piping, pumps, valves, hydrants, and monitors. The underground firewater system should be a loop with branches off it. This means that, if the underground line is broken or blocked at any point, firewater can still reach the point where it is needed.

PORTABLE FIRE EXTINGUISHERS

Portable fire extinguishers include both self-contained fire extinguishing equipment that can be carried by one person and wheeled units that can be handled by one or two people. Due to their limited capacity, portable fire extinguishers are designed to control fires that are just starting or that are of limited size.

LOCATION

Portable and wheeled or cart-type fire extinguishers should be located near the equipment to be protected, but not so close that they can become involved in the fire or that a person cannot reach them. They will generally be placed along normal paths of travel so that they are immediately available.

The suggested distance from their point of use is between 5 and 15 meters. From any grade level point in a process plant, the maximum horizontal distance to a dry chemical extinguisher should not exceed 15 meters. Extinguisher locations should be conspicuous, clearly marked, and visible from several directions. The locations should not be blocked with materials or equipment that might conceal them or impede access to them.

Portable extinguishers must be tested on a regular basis and that records of the date of test, test pressure, and name or initials of person making test shall be recorded on a metal tag or equally durable material and affixed to the shell of each extinguisher passing the hydrostatic test. A log may be kept instead of using the tag system. The extinguisher shell may be stamped with the hydrostatic test date instead of affixing a tag.

Fire extinguishers must be maintained and checked properly. The check should include a thorough examination of mechanical parts (hose, shell, puncture lever, and other operating components), extinguishing material (e.g., ensure there is adequate powder, that the powder is free flowing and designed for that extinguisher), and expelling means (cartridge is of proper size and weight for that extinguisher, and contains the appropriate gas).

TYPES

Table 9.3 provides guidance regarding the selection of portable extinguishers.

Water extinguishers

The superior cooling capacity of water over other extinguishing agents makes it particularly effective on fires involving ordinary combustibles such as wood, paper, fabrics, or rubber. Water extinguishers do not require extensive cleanup after use and they are noncorrosive to electronic circuitry, unlike dry chemical extinguishers. When water extinguishers are subject to freezing weather, antifreeze is added.

Table 9.3 Selection of Portable Fire Extinguishers

Class A—Ordinary Combustible Hazards

Class “A” fires consist of ordinary combustibles such as wood or paper.

Water can be used. Multipurpose dry chemical may be considered for some warehouse facilities and offices where lightweight fire extinguishers are desirable for easier handling.

Extinguishers for Class “A” fires should be placed so that no point in the protected area is more than 25 meters from an extinguisher.

Class B—Flammable Liquids and Gases

Class “B” fires consist of flammable liquids and gases.

The following fire extinguishing materials can be used:

- Dry chemical
- Carbon dioxide
- Multipurpose dry chemical

Extinguishers for Class “B” fires should be placed so that no point in the protected area is more than 15 meters from an extinguisher.

Class C—Electrical Hazards and Delicate Electronic Equipment

Class “C” rated extinguishers shall be available in areas where energized electrical equipment is located. Class “C” fires are extinguished either with CO_2 (carbon dioxide) or a dry chemical (difficult to clean up and may damage the equipment).

CO_2 extinguishers

CO_2 is stored in extinguishers in the liquid phase. It vaporizes when released, thereby smothering a fire by excluding the air (oxygen) needed for combustion. CO_2 extinguishers are preferable to water or dry chemical extinguishers where water damage and fouling of delicate electrical, electronic, or laboratory equipment cannot be tolerated or where cleanup is a consideration.

If a CO_2 extinguisher is discharged in a confined space, then that space must be ventilated once the fire is extinguished.

Dry chemical extinguishers

Many types of dry chemical extinguishing agents are available. Those shown below are widely accepted in the process industries:

- Sodium bicarbonate
- Potassium bicarbonate base (purple K)
- Monoammonium phosphate

Sodium bicarbonate was the original dry chemical extinguishing agent. The chemical currently available is a mixture consisting primarily of sodium bicarbonate with various additives to improve flow and storage characteristics. Chief among the additives is a silicone polymer. It is used to prevent moisture absorption and consequent caking of chemical. It works by interrupting the propagation of the flame. Its electrical resistivity is high, and it is nontoxic. This agent may be used for extinguishing fires involving flammable liquids, gases, and electrical equipment. It is not effective in extinguishing deep-seated fires in ordinary combustibles.

Potassium bicarbonate chemical, whose physical properties are similar to sodium bicarbonate, is effective at extinguishing fires involving flammable liquids and gases. It is also suitable for use on fires involving electrical equipment. It is not effective in extinguishing deep-seated fires in ordinary combustibles.

Monoammonium phosphate-based chemical is effective in controlling and extinguishing fires involving flammable liquids and gases, ordinary combustible materials, and electrical equipment. It is recommended where piped water is not available, where freezing conditions are expected, or where a combination of different classes of hazards exists. It has physical properties similar to the sodium bicarbonate chemical but is more effective on flammable liquid fires. It is corrosive to electronic circuitry and it should not be mixed bicarbonate dry chemicals. A chemical reaction can occur in the extinguisher that generates CO_2 and other gases—the pressure buildup could rupture the extinguisher.

TRAINING

Those who may have to control or fight fires must be thoroughly trained—this is obviously a high-risk activity. In particular, workers must know when *not* to get involved; they must understand that, if a fire becomes big enough, the response needs to be escalated and the situation managed by a properly trained emergency response team.

Drills should be conducted regularly. They should include as a minimum the following:

- Capabilities and limitations of the firewater system and its components
- Fire-pump operation and water deliverability
- Hose handling techniques
- PPE
- Foam making requirements, supplies, and limitations where foam is available
- Manpower allocations to fight fire
- Fire situation chain of command
- Use of monitors and stationary equipment

CHAPTER

10 Safety in design

CHAPTER OUTLINE

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INTRODUCTION

As explained in Chapter 1 the engineering information provided in this book generally uses the SI (*Le Système international d'unités*) metric units. However, much of the information to do with regulations and standards, particularly in the United States, is based on the English or 'customary' units such as feet (ft.) and pounds (lb.). In most cases these English measurements have been converted to metric.

UNITS OF MEASUREMENT

Although most engineering work is conducted in metric units, much of the information to do with engineering regulations and standards, particularly in the United States, is provided in British units such as feet (ft) and pounds (lb). Providing information in both systems is distracting. Therefore, the units of measurement used in this book are generally in metric only (with a few occasional exceptions).

FIRE PROTECTION

The following structural materials are commonly used in process facilities:

1. Cast-in-place reinforced concrete
2. Precast reinforced concrete
3. Masonry
4. Structural steel

Of these four, structural steel is generally the most preferred. It is economical and can be readily modified or strengthened to cater for additional loads on the structure. However, unlike the first three materials in the list, unprotected structural steel members do not possess inherent fire resistance. They lose about half of their strength at 500°C and rapidly lose more strength as the temperature rises. This is a critical drawback given that the temperatures of pool fires can reach 1,100°C very quickly. In order to overcome this problem, structural steel is covered in a fireproofing material in those parts of the facility where it could be exposed to fire.

PASSIVE FIRE PROTECTION

The best form of fire protection is passive, i.e., it is effective regardless of actions taken by individuals or active safety systems. Fire protection generally includes the following items:

Sufficient separation between equipment items
Fire protection barriers and walls to prevent the spread of fire
The use of fire-rated insulating materials to protect the integrity of structural steel members, risers, vessels, and other safety critical items.

FIREPROOFING

Fireproofing insulation is often applied to equipment and steel supports in process facilities. Fireproofing provides resistance to fire so that critical structures remain standing and critical control systems continue to operate until the fire is brought under control. Asbestos was commonly used for fireproofing but has been replaced with a range of cement-based products. Intumescent coatings work by quickly swelling to four times their original thickness, thus insulating the structure that they are protecting. If a vessel or column requires insulation for other reasons, cost-effective fireproofing can often be accomplished by using stainless steel weather-jacketing over the insulation, provided the insulation is suitable for the fire temperature. Water spray or deluge systems can replace fireproofing for vessel protection and should be provided when vessel contents are reactive.

Fireproofing is typically designed for the following conditions:

- To keep structural steel below 540°C.
- To keep vessel skirts and pipe bridges below 540°C (fireproofing is generally only warranted on vessel and column skirts, not on the vessels themselves).
- To keep electrical circuits below 140°C.
- To prevent BLEVEs (Chapter 4) of vessels containing light, liquid hydrocarbons.
- It is also used for critical instrumentation systems. Fire losses can be minimized by keeping essential control circuitry operational during the early stages of a major fire and by minimizing shutdowns resulting from minor

fires. Protection should permit emergency function for at least 20 minutes with fire environment temperatures up to 1,100°C.

The following should also be considered for fireproofing protection:

- Fired equipment, including heaters and furnaces that handle flammable materials that will ignite when released.
- Rotating or reciprocating mechanical equipment, such as pumps or compressors, that handles flammable materials.
- Drums, exchangers, columns, and similar operating vessels that handle flammable materials and have a volume of more than 3,500 liters.
- Plot-limit piping manifolds that contain flammable materials and 10 or more valves.
- Tanks, spheres, and spheroids that contain flammable materials including their drainage and relief path and impounding basins.
- Structures that support relief and safety-critical vent headers.
- Piping in which there is no normal fluid flow, thus preventing removal of heat by the contents of the line.
- Instrumentation and control systems that are critical to safety.

Conversely, fireproofing is not generally warranted for the following situations:

- The value of the structure and supported equipment is low when compared to the cost of fireproofing.
- Failure of a support member would not cause failure of the structure or equipment. Thus, wind and earthquake bracing and other secondary members, such as supports for stairs, platforms, and walkways, are not normally fireproofed.
- The structure is located well away from a fire source.
- The fire would cause failure or serious damage to supported equipment whether or not the structure was fireproofed.
- The structure supports piping that is not carrying flammable liquids. Piping carrying only gases does not normally justify fireproofing of the supports because the risk of a hydrocarbon pool fire is low.

During a major fire, the fireproofing will itself eventually be destroyed. Therefore, it is important to decide how long it is intended that the fireproofing be effective. A working number of 3 hours for onshore facilities and 2 hours for offshore structures are often used, but this number can be reduced if it can be shown that the fire will burn itself out before then because the inventory of flammables will have been consumed.

Cement-based fireproofing materials are not necessarily ruined after exposure to a short-duration fire. The usefulness of the remaining fireproofing will depend on how much water of hydration was lost, which itself will be a function of the intensity and duration of the fire. Long-term environmental exposure does not generally have much effect on fireproofing materials. Lightweight materials and noncement-based materials can be protected by top-coating.

Design of structures must include the weight of fireproofing, which can significantly add to the total deadweight load. This extra weight can be a significant design issue, particularly for offshore structures, and may justify the use of the more expensive proprietary types of fireproofing that has a lower density.

FIREPROOFING MATERIALS

Effective fireproofing should possess the following qualities:

- Low thermal conductivity
- Low density
- Incombustible
- Good bonding strength
- Resistance to weathering, hydraulic erosion, and thermal shock
- Hardness
- Good vapor permeability and porosity
- Able to withstand a direct flame impingement of up to 2,000°C

Probably the most widely used passive fireproofing system for structural steel is cementitious concrete. When initially exposed to high temperatures, such as in the case of a fire, concrete absorbs heat through an endothermic heat of reaction when chemically bound water is released from the crystalline structure.

Essentially, concrete is a "hard sponge" with a network of small conduits or capillaries allowing directional passage of water from interior to exterior regions to cool hot contact surfaces. However, as moisture moves within the concrete, small amounts of soluble salts are in solution which deposit within the pores of the concrete as the water quickly evaporates during the fire event. As the salt deposit fills-in the voided areas, the concrete pores become blocked and do not allow further transfer of water to cool high-temperature contact surfaces. Therefore, the water accumulates behind this barrier and is phase changed from a liquid into a gas.

During a fire, high-temperature gradients form within concrete. Consequently the hot surface layers tend to separate and spall from the cooler interior of the body. The formation of cracks is propagated at joints, in poorly consolidated parts of the concrete or in planes of the embedded metal items such as structural steel members and/or reinforcing steel bars. Once exposed, the steel will conduct heat and at a greater rate. Also, firewater applied to the hot concrete can cause damage. It causes a large reduction in concrete material strength because severe temperature gradients develop.

Fireproofing concrete placed over structural steel members will generally incorporate clips and welded-wire mesh detailing to maintain fireproofing integrity during a fire event. However, the clips and mesh are also subject to corrosion and can initiate concrete cracking during the ongoing corrosion activity of these items.

Unseeen deterioration in the form of embedded metal corrosion can be hidden from view and not readily visible, in some cases, until it is too late. As the steel corrodes, its metallurgy changes and the corrosion products occupy more space than the parent material. As such, significant tensile stresses are exerted on the concrete in the immediate proximity of the corroding steel member. Although inherently strong in compression, concrete is relatively weak in tension. Therefore, unrestrained portions of the concrete mass will crack at the corroding member interface.

FIREPROOFING INSULATION

Fireproofing insulation is often applied to equipment and steel supports in process facilities. Fireproofing provides resistance to fire so that critical structures remain standing and critical control systems continue to operate until the fire is brought under control. Asbestos was commonly used for fireproofing but has been replaced with a range of cement-based products. Intumescent coatings work by quickly swelling to four times their original thickness, thus insulating the structure that they are protecting. If a vessel or column requires insulation for other reasons, cost-effective fireproofing can often be accomplished by using stainless steel weather-jacketing over the insulation, provided the insulation is suitable for the fire temperature. Water spray or deluge systems can replace fireproofing for vessel protection and should be provided when vessel contents are reactive.

STAIRWAYS, RAMPS, AND PLATFORMS

An overview of the design requirements for stairs, ramps, and platforms is provided in this section; fixed ladders are discussed in the next section. The material here does not provide detailed guidance regarding the measurements and specifications—such information can be obtained from the many of the standards and regulations that cover these items.

Ramps are used in areas where there is high traffic and/or frequent use of wheeled carts that are used to move equipment. Ramps will be used where the elevation change is small and there is sufficient room to allow for a gentle slope.

Stairs should generally be used over ladders in the following situations:

- When routine movement between two levels is required
- For routine tasks such as gauging, inspection, and maintenance
- Employees could be hand-carrying heavy or bulky tools and/or equipment
- There is a potential for exposure to hazardous materials at the elevated location and immediate escape is required

REGULATIONS AND STANDARDS

The design of stairways, ladders, and ramps is covered by many regulations and standards, some of which are listed below. These standards provide considerable detail to do with topics such as the spacing between stair treads and the height of hand rails:

- ANSI A64.1-1968
- ASTM F 1166-95a, Standard Practice for Human Engineering Design for Marine Systems, Equipment and Facilities, 1995
- ABS Guidance Notes on the Application of Ergonomics to Marine Systems, January 1998
- DOT/FAA/CT-96/1, Human Factors Design Guide for Acquisition of Commercial-Off-The-Shelf Subsystems, Non-Developmental, and Developmental Systems, January 15, 1996
- MIL-STD-1472F, Department of Defense Design Criteria Standard, Human Engineering, August 23, 1999.
- MIL-HDBK-759C, Department of Defense Handbook, Human Factors Engineering Design Guidelines, March 31, 1998
- Occupational Health and Safety Administration (OSHA) 1910.24. Walking-Working Surfaces. Fixed Industrial Stairs

TERMINOLOGY

Figure 10.1 is a sketch of typical industrial stairs.

Angle of ascent/inclination

The angle of ascent for stairways should be in the range 30°–50° and the vertical elevation should exceed 24 inches (610 millimeters).

Handrail

The rail provided on the open side of an elevated flat walking or working surface to protect workers from falling to a lower surface. It is also called a guardrail.

Riser

The height from one tread to another. They should be spaced equally, and the first or bottom tread should be the same height above the walking surface as the risers are from one another.

Tread

The step on which workers stand. The tread depth should be consistent for a given set of stairs. The top tread should be on the same level as the adjacent walking surface.

Overhead clearance

A minimum height between each stair tread and any obstruction directly overhead should be specified.

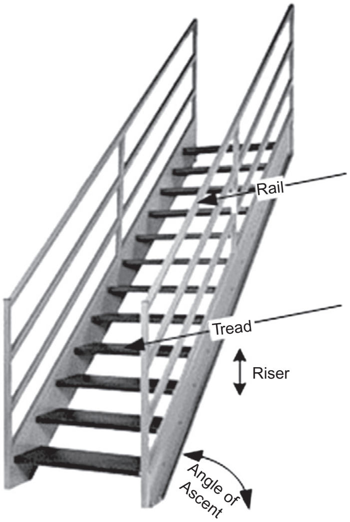

FIGURE 10.1

Stair terminology.

Stair width

Stairs that are designed for two-way traffic, that are an emergency egress route or that may require stretcher access should be 44 inches (1,120 millimeters) or more in width. One-way stairs that are infrequently used and that do not require stretcher access should be 30 inches (760 millimeters) or more in width.

SPIRAL/WINDING STAIRS

Spiral stairs should not generally be used. Winding stairs can be installed on tanks and similar round structures where the diameter of the structure is not less than about 2.5 meters. The stair should ascend in a clockwise direction to allow the stair rail to be on the right-hand side during descent. A stair rail between the tank and stairs is required if the gap between the tank/tank insulation and stairs is greater than 6 inches (CAL OSHA specifies 8 inches). Intermediate landings are not required.

In areas with significant snow, the stairway should be on the sheltered side of the tank.

LANDINGS

If a stair has a vertical rise of 20 feet or more, intermediate landings should be provided every 12 feet. (Occasional use stairways may not require intermediate landings.) The landings should be as wide as the stairs and should have handrails.

Where doors or gates open directly on a stairway, a platform should be provided; the swing of the door should not reduce the effective width to less than 20 inches.

DESIGN LOAD

Stairways should be built to carry five times the normal anticipated live load, but not less than a 1,000 pounds moving concentrated load. The design load for walkways and platforms should be the maximum probable loads produced by the intended use. The design load should be increased as necessary for any machinery or equipment which may add to the live load.

STAIR RAILS

Railings are required for floors and stairways that have open sides and for platforms that have a significant elevation over the deck/grade around them. The following guidance to do with the design of stairs is provided:

- A single-tier stair rail is used to maintain balance while going up- or downstairs, and should be installed on the enclosed side of stairs.
- A two-tier rail, used to maintain balance and prevent falls from stairs, should be installed on all open sides of stairs.
- Stairs with three or more steps should be equipped with stair rails.
- Stairs wider than 88 inches (2,240 millimeters) should be equipped with a single-tier stair rail in the center.
- Stair rails should be highly visible, often of a different color from the stairs themselves.
- Toeboards are required if a person could slip under a railing.

STAIR TREADS

Each tread should be painted to make its leading edge visually distinctive from the color of the rest of the tread or the walking surfaces to which it is connected. When the stair tread and/or deck grating is yellow, the leading edge should be painted a bright red. When the stair treads and/or deck grating is galvanized steel or painted a gray color, the leading edge should be painted a bright yellow.

All treads should be slip resistant; steel stairs should have treads made of serrated grating. If floor plate is used, then weep holes for drainage should be provided.

RAMPS

Ramps are used to minimize tripping hazards and to facilitate use of wheeled equipment such as some fire extinguishers, oxygen/acetylene rigs, and hand carts.

Ramps can be used if the angle of inclination is less than 20° (15° preferred) and the change in vertical elevation is less than 24 inches. The 24 inches limit may not apply if the ramp is a primary means of access/egress in an emergency and a ramp would more efficiently allow egress. Nevertheless, the 20° angle of inclination limit should still be maintained.

Ramps should have a nonskid surface if the angle of inclination is greater than 10° and should be provided with handrails on the open side of the ramp if the vertical distance from the ramp to the nearest surface is greater than 24 inches (610 millimeters).

Ramps should have a minimum width of 36 inches (950 millimeters) and should have landings at the top and the bottom. The landings should be at least as wide as the ramp. There should be adequate space at the landings for people and the equipment that they are carrying or moving to change direction.

FIXED LADDERS

Fixed ladders are widely used in the process industries. General guidance to do with their design is provided below (portable ladders, wooden ladders, and elevators are not discussed). The regulations and standards to do with ladders are listed in the section to do with stairs; they provide detailed guidance on measurements.

Ladders are typically used in the following applications:

- Access to elevated tanks, towers, and overhead traveling cranes
- Secondary access and escape
- Maintenance access to platforms or other access which are used infrequently or where stairways are impractical

They should never be used as the primary mode of escape.

GUIDANCE

The design and installation of fixed ladders should consider the following guidelines (all measurements are approximate and will vary according to local standards and regulations):

- Ladders should be vertical whenever possible. Where clearance problems require the ladder to be sloped, the slope should not exceed 15° forward and should not slope backward under any circumstances. The angle of inclination for fixed vertical ladders should be between 75° and 90° from the horizontal.
- Fixed ladders should be straight throughout their length.
- Ladders should be oriented so that a person faces the structure or vessel while climbing.
- Side access ladders are preferred to the front access style for the reasons referred to above.
- The design load should be determined by the anticipated usage of the ladder, but not less than a single concentrated load of about 120 kilograms.

- The minimum clear length of rungs or cleats should be 0.4 meter.
- Rungs and side rails should be free of splinters, sharp edges, burrs, or projections which may be a hazard.
- Side rails which might be used as a climbing aid should be of such cross sections as to afford adequate gripping surface without sharp edges, splinters, or burrs.
- The perpendicular distance on the climbing side of the ladder from the centerline of the rungs to the nearest permanent fixed object should be 1 meter or more.
- The perpendicular distance on the back side of the ladder from the centerline of the rungs to the nearest permanent fixed object should be 200 millimeters or more, except when unavoidable obstructions are encountered.
- The step across distance from the nearest edge of the ladder to the nearest edge of equipment or structure should not be more than 0.4 meters.
- There should be a rest platform every 10 meters.
- Ladder rungs should be equally spaced throughout including the first rung below the landing.
- Ladder extensions should extend at least 3 meters above parapets and landings.
- Rung spacing should be around 0.3 meter center to center and should be uniformly spaced throughout the length of the ladder.
- A barrier should be placed on the back side of ladders that can be inadvertently climbed on the wrong side.
- Ladder rungs should be made of steel, protected from corrosion, and made of nonslip materials.
- Maximum heights of unbroken ladders should be 30 feet (9,145 millimeters) for ladders with cages and 20 feet (6,100 millimeters) for ladders without cages.
- Where vertical ladder heights exceed 30 feet (9,145 millimeters), intermediate landings and separate multiple ladder runs of equal length should be provided to cover the required vertical distance.
- Where transition from one vertical ladder to another is accomplished using a side-step platform, the horizontal separation between the two ladders should be a maximum of 18 inches (460 millimeters). A rung on the parallel ladder to the intermediate platform should be at the same height as the platform.
- All vertical ladders must be attached to permanent structures and should not be attached to removable items (e.g., manways or handrails), or interfere with the removal of any item.
- Ladders should be located so the maximum distance from ladder centerline to any object, which must be reached by a worker from the ladder, should not exceed 30 inches (760 millimeters).
- Vertical ladders used to access tank openings or pressure vessel manways or any other opening equipped with a hinged cover should be located so the cover swings away from the ladder.
- More rigorous standards apply to ladders and related equipment that is in the wave zone of an offshore platform.

SAFETY CAGES AND GATES

Fixed ladders should have a cage around them so that, were a worker to fall, he or she would fall down, not out. Ideally the bottom exit from the ladder cage should be oriented at 90° from the ladder itself. There have been occasions where a person fell down a ladder, hit the deck, and then fell over the handrail down to the level below.

Figure 10.2 shows a vertical ladder on the side of a column of a semisubmersible platform. While the platform was under construction, a person fell down the ladder and then flipped over the handrail. The total fall was about 25 meters. He died. The handrails appear to be of the required height (1070 mm.), but the cage seems to terminate higher than the OSHA required height of between 7 and 8 feet (2.1 to 2.5 meters) above the deck or access platform.

Two similar incidents that resulted in fatalities and which involved vertical ladders occurred at about the same time. These incidents led to the adoption of the following standard:

> *When a caged ladder is located within 6 ft. of the edge of the deck, which has a maximum fall distance greater than 15 ft., special consideration is required. Either the bars on the cage on the deck edge side should be extended to the handrail, or the handrails should be raised to within 24 in. of the bottom of the safety cage for 48 in. on either side of the ladder centerline. The extended bars on the cage should not restrict access to the ladder or to the walkway.*

Figure 10.3 shows a better design. The handrails are raised to within 600mm of the bottom of the ladder. Figure 10.3 also shows that the vertical ladders terminate

FIGURE 10.2

No safety cage.

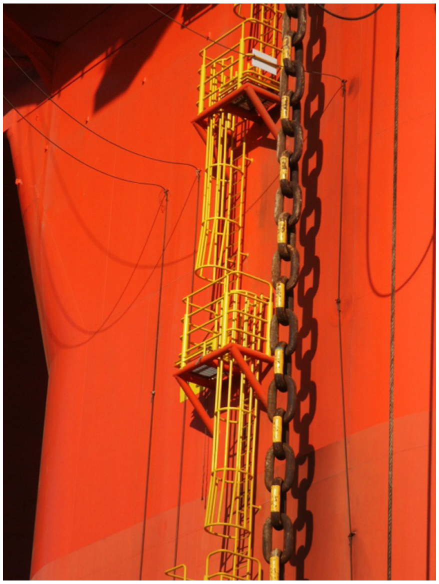

FIGURE 10.3

Safety cage.

at the top in a manner such that a person sidesteps on to the platform. This will result in a person being able to see where he is placing his or her feet rather than having to step backward when descending down a ladder that terminates in a step-through configuration. The sidestep configuration has another advantage, in that it requires no transfer of the hands from the ladder rungs to the stringer when reaching the top.

A self-closing safety gate covering the full width of the opening between the ladder stringers should be installed at the top of each ladder. The following guidance to do with safety gates is provided:

- They can resist the full weight of a person in both the vertical and horizontal direction.
- Where ladders provide access to small platforms that do not provide sufficient space for the self-closing gate to swing horizontally, manually operated gates that open and close via a vertical swing should be used.
- The gate should open away from the person climbing up the ladder.
- Chains should not be used.

RUNGS AND STRINGERS

Ladder rungs should be used to hold on to when climbing. The use of stringers should be discouraged because there is an increased chance that their hand will slip. Angular or flat bar increases the chances of someone's hand slipping and should not be used.

The following guidance applies to the design of the rungs on a ladder:

- The top rung (as well as the top rung used to access an intermediate platform) on all vertical ladders should be top flush with the top walking surface (or side-step platform).
- Vertical spacing between the centerline of the rungs should be between 11 inches (280 millimeters) and 12 inches (305 millimeters) depending on what is required to provide equal spacing between rungs for the entire length of the ladder from the bottom landing to the top rung.
- Where multiple runs of ladder lengths are required to cover the vertical distance, the same rung spacing should be used for all run lengths where possible.
- The top surface of a rung should be covered with a nonslip material, especially where ice or snow is expected.
- There should be a stringer on each side of the ladder for the full length of the ladder.
- There should be a clear distance behind the rungs of approximately 8 inches (205 millimeters).
- There should be no obstructions above the top rung.

INTERMEDIATE PLATFORMS

Ladders should not be used as a work platform. If ladders provide access to a work site on the side of tank, vessel, or other structure, then a work platform should be provided so that the worker can safely use both hands and is protected from falling were he or she to lose balance. Intermediate platforms should have sufficient clear standing area in front of the ladder and should have clearance from both sides of the ladder centerline.

If an intermediate platform is either cost-prohibitive or impractical, a harness in combination with the climber safety rail provides true fall protection.

All intermediate platforms should be equipped with handrails and toeboards on all sides not used as access to a vertical ladder.

WORK PLATFORMS AND WALKWAYS

Elevated work platforms are needed in those locations where workers must reach, lift, produce force, or in general perform tasks which cannot be safely and easily accomplished from an existing standing surface. Standard railings and toeboards should be provided on the open sides of all exposed stairways and stair platforms.

The height and size of the platforms should be such that the worker can carry out his or her tasks without having to assume an awkward or unsafe body posture. Therefore, before the platform is designed, it is important to conduct a human factors analysis of the tasks that are likely to be performed at that location.

Handrails and toeboards

Handrails and toeboards are usually needed at the edges of platforms and walkways unless the gap between the platforms of walking surface is so narrow that a person cannot fall through it.

Handrails should be made of pipe—square handrails should never be used.

Toeboards help prevent a person from sliding off the platform under the handrails. They are generally 100 millimeters high.

If it is possible that items being carried along a walkway could slip between the handrails, then mesh screen or netting should be installed.

Tank gauging platforms

A clearance of at least 2 feet should be provided around gauge and sample hatches so that the worker can always be upwind or the hatch.

Connected tanks

Independent platforms and walkways are preferred for all working and walking surfaces of tanks. However, tank roofs on noninsulated tanks may be used for these purposes if the slope of the roof does not exceed 2 inches per foot, a nonskid surface is applied to and properly maintained on all working and walking surfaces, the tank roof is properly reinforced for live load floor support, and the tank content is having noncorrosive material.

The walking surface should be clearly defined by color contrast. The deck of the roof should be at least 1/8-inch thick and structurally capable of supporting maximum probable live load and should be inspected annually to assure its structural integrity

When two or more tanks are interconnected, a second means of egress is needed if a chemical leak or fire could block the main egress. Tanks in water or other service which present no potential hazard exposure are exempt from this requirement.

The design and use of ladders offshore poses special concerns, including the following:

- Ladders should not be installed near deck edges, where possible.
- A fall from the deck could be much greater than the ladder height.

EMERGENCY SHOWERS AND EYEWASHES

Many industrial facilities handle corrosive chemicals that can cause serious burns or tissue damage if they contact a person's skin. If a worker is splashed with one of these chemicals, he or she needs to be able to quickly get to an emergency shower quickly in order to dilute and wash off the corrosive or burning liquid with large quantities of potable water. If the chemicals can enter a worker's eye, then an eyewash is also needed.

As a rule of thumb, if safety goggles are required in a particular area, then a safety shower/eyewash should be provided. Another rule of thumb is that if a section of the facility is demarcated with a "Do Not Cross—Hazardous Chemicals" line, then, once more, a safety shower should be installed. Guidance as to whether a safety shower is required may also come from the chemical's Material Safety Data Sheets (MSDS).

REGULATIONS AND STANDARDS

In the United States, safety shower and eyewash standards are provided by OSHA in their 29 CFR 1910.151(c) which states:

> *Where the eyes or body of any person may be exposed to injurious corrosive materials, suitable facilities for quick drenching or flushing of the eyes and body should be provided within the work area for immediate emergency use.*

The regulation refers to ANSI Z358.1, last updated in the year 2009. Companies operating in California should follow Cal-OSHA 5162, which also refers to the ANSI standard.

Other standards to do with safety showers include the following:

- DIN 12899-3: 2008
- EN 15154-1: 2008
- EN 15154-2: 2006
- ISO 9001: 2000

British Standard 91/29234 DC covers electrical installations in buildings in locations containing a bath tub or shower basin.

RISK ASSESSMENT

If a safety shower has to be used by an injured worker, then it is self-evident that the company's safety management systems have failed. It is obviously much better to have a system, whereby no one is ever hurt by harsh chemicals than to treat that person after the event.

The basic principles of risk management and inherent safety have already been discussed. They are listed below with examples to do with safety showers:

1. Remove the hazard
   - Replace the harsh chemical with one that is more benign
   - Eliminate the need for samples, or have an automated closed-loop sample system
   - Use closed drain systems
2. Reduce the consequence of the hazard
   - Use canned (self-contained) pumps
   - Use double seals on pumps

3. Reduce the likelihood of the hazard
   – Use low maintenance seals
   – Enclose sample hatches
   – Provide additional level gauges on tanks
4. Install post-event safeguards
   – Safety showers

These actions should be taken in the order shown. Therefore, when faced with the dangers to do with workers being splashed by harsh chemicals, the use of safety showers should be the last action taken.

RELEASE POINTS AND LOCATION

Before designing a safety shower system, it is necessary to identify the most likely release points and to determine the likelihood of a person being present if a release does occur at that point. Release point identification can be carried out as part of a process hazards analysis.

Typical release points are as follows:

- Sample points
- Pump seals
- Tank overflow lines
- Low-point drains

Once the release points have been identified, the following guidance can be used to determine where a safety shower and eyewash station should be located:

- The ANSI standard requires that a person be able to reach an emergency shower within 10 seconds, but it does not specify a distance. One company interprets this to mean that the shower should be no closer than 10 feet nor further than 50 feet from the release point. NFPA 101 suggests that a distance of 75 feet can be traversed in approximately 10–15 seconds.
- The shower should be easy to identify, even if a person is in pain due to the chemical contact, or if the chemical has partially covered their eyes, safety glasses, or face mask.
- The shower should be identifiable in bad light and bad weather.
- Once a person reaches the shower, he or she should be able to identify and use the handle without difficulty.
- It should be away from the most likely spray paths.
- It should be on the same level as the release point. The affected worker should not have to negotiate stairs or ladders.
- It should be in a straight line from the release point.
- It should be outside the chemical hazard area (yellow line area) and upwind of potential leak sources when toxic gases may be released.
- It should be in a well-lighted area but at a safe distance from electrical equipment and power outlets.

- Change room showers may serve as substitutes for safety showers provided proximity and accessibility are suitable for the particular chemical hazards involved.
- If more than one person could be splashed with the hazardous chemical, then a second safety shower should be provided.

The items discussed above are illustrated in Figure 10.4, which is based on the standard example. It shows the location of a safety shower adjacent to pumps that could leak hazardous chemicals from their seals.

The following points should be noted with regard to Figure 10.4:

- The safety shower is located outside the hazardous chemical area, i.e., behind the yellow line. Hence other workers can help the injured person in the safety shower without having to wear special protective clothing themselves.
- The stop switch for the pumps is located near to the shower but, once more, it is not in the hazardous area. If someone comes to help the person in the shower, probably the first thing that they should do is to stop the pumps so that no one else is injured.
- The entrance to the safety shower faces the pump seals. An injured person can go directly into the shower without having to turn corners or navigate around equipment.
- The shower is located upwind of the pumps.

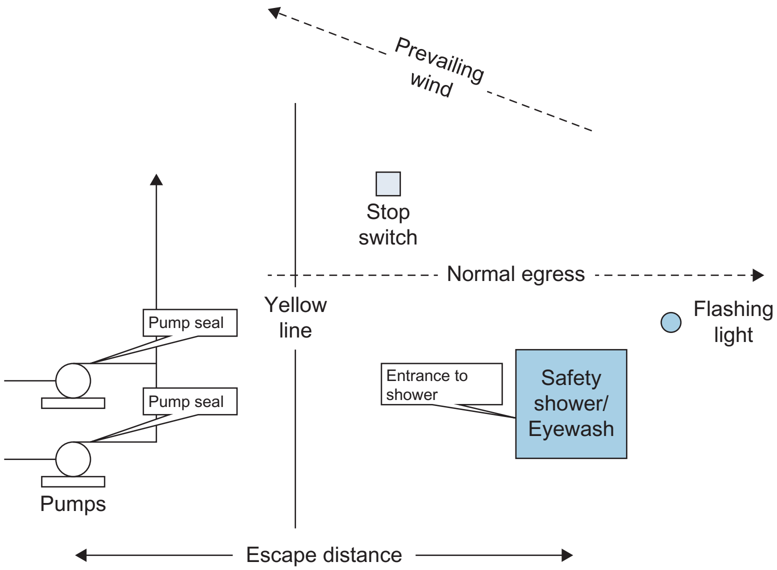

FIGURE 10.4

Representative safety shower layout.

- The shower is on the same level as the pumps; the injured person does not have to go up- or downstairs.
- The normal egress route and the route to the shower are basically the same; the injured person can move in the normal direction. He or she does not have to think as to which direction to go.
- The flashing light that indicates that the shower is in use is located where it can be seen from multiple locations.
- The distance from the release point to the shower is short.

SAFETY SHOWER DESIGN

Figure 10.5 is a sketch that illustrates the principal components of an emergency shower.

The following are the key elements of the shower (the labels correspond to those shown in Figure 10.5).

- *Feed pipe.* Water flows up this pipe—usually from an underground piping system containing potable water. The material of construction should be

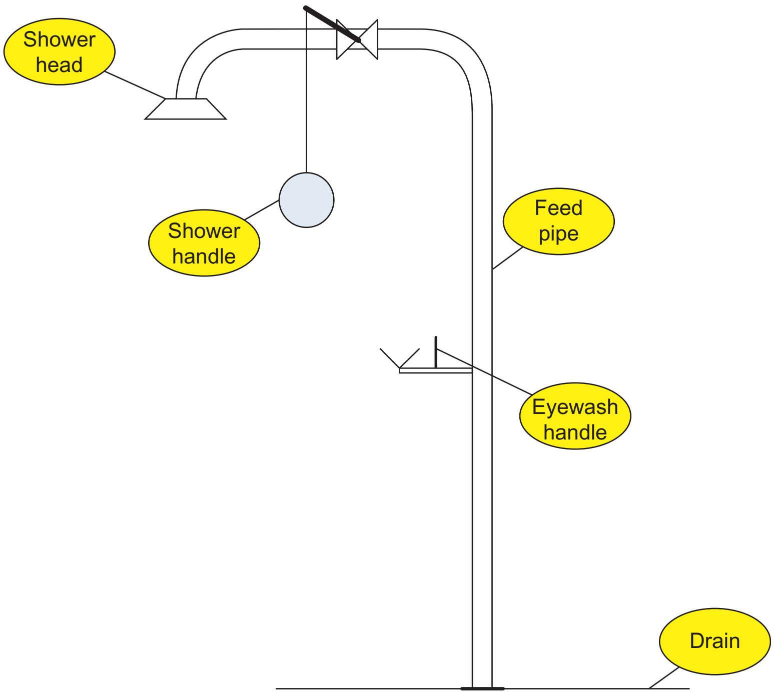

FIGURE 10.5

Components of an emergency shower.

suitable for potable water service and resistant to corrosion from the hazardous chemicals that may be present.

- *Handle.* The person using the shower pulls this handle. The handle should be easy to see and reach. The water should continue to flow once the user has released the handle. Similarly with the handle on the eyewash—once opened it should remain open.
- *Showerhead.* The shower head should have adequate diameter to cover a person fully and should have sufficient capacity to deliver enough water. It should also be at a height suitable for most people. (Detailed guidance as to dimensions is provided in the DIN standard.)
- *Eyewash.* The eyewash station is integrated into the safety shower unit.
- *Drain.* The water must flow away from the shower. Since the water may be contaminated, it may need a special drain line.

Flow rates and pattern

The flow of water should provide a wide enough cross section to wash all parts of a person's body and the water should be spread evenly. Guidance to do with dimensions is provided by the ANSI and DIN standards. The following are typical parameters:

- The spray pattern for a safety shower should have a minimum diameter of 20 inches at 5 feet above the surface on which the user stands.
- A flow rate of 30 gallons per minute.
- The flow of water to the eyewash should be 3 gallons/min (11.4 l/min) but should not be so high as to cause eye injury.

If a piped supply of potable water may not be available, then a dedicated water tank can be provided. The tank should have a low-level alarm and should be tamperproof so that workers do not use it for drinking water.

Visibility and accessibility

The injured person must be able to reach the safety shower quickly and with minimal hindrance even when the weather is bad or at night. There should be a clear pathway from the potential release sources to the shower. The shower itself should be in a clear space and should not be obstructed by equipment, piping, or loose materials.

Some companies provide modesty curtains around the shower. However, these curtains may hamper the worker as he or she attempts to enter the shower. Also it is likely that if someone is severely burned that they are not going to worry about modesty too much. An alternative is to enclose the shower with safety glass panels and a door with a friction catch.

Figure 10.6 shows signs that can be used to identify the shower.

FIGURE 10.6

Signs.

Alarms

An alarm that is activated whenever either the eyewash or safety shower is turned on should be provided. The alarm should sound at a place that is attended during all working hours, such as control rooms. Its alarm should appear on a visual display board in the attended location to identify the location of the emergency. Also, a flashing red light should be located close to the shower.

Electrical area

When the shower is turned on, some of the water may splash outside the immediate area of the shower itself, especially if the person using the shower has failed to close the modesty curtain. Therefore, it is important that there be no electrical equipment in the area that could be damaged by the water.

Freeze protection

The water supplied to a safety shower or eyewash unit should be at ambient temperatures (15°C–35°C).

If the ambient temperature falls below freezing, there is a danger that the water in the safety shower system will freeze because it is not flowing. In order to prevent this from happening, the safety shower lines can be drained. However, the system should not have such a large capacity that a person has to wait for long for it to fill up if he or she turns on the shower.

If a "dry pipe" system is used, there is also a danger that moisture-containing air will enter the system; the water in the air will freeze and gradually accumulate in the piping. To overcome this problem, the safety shower piping system can be kept at under pressure with dry air.

Another potential problem to watch for concerns safety shower systems that use a "Christmas tree" arrangement of piping. If someone trips the flow to one shower, the entire system will fill up with water, hence the lines to those showers that were not tripped will have a dead-leg of water that can quickly freeze—leading to line rupture when the water is thawed.

Heat protection

When ambient temperatures are high, the water in the safety shower system can become hot enough to scald someone using the system. One way of handling this problem is to put a high-temperature bleed valve in the shower. If the temperature of the water rises above a set point, the bleed valve will open, thus allowing water to flow out of the shower into a drain. Eventually, cooler water will come through, and the bleed valve will close.

Waterlines above grade in the sun can also be insulated and have a reflective coating.

Sunlight is not the only source of heat. If the waterline to one of the showers happens to run close to a steamline or to a hot process line, the stagnant water in the shower line could become very hot.

Enclosures

Safety showers in exposed areas where the temperature regularly drops below 40°F require enclosures.

- The opening to the enclosure should have a see-through section.
- A wool blanket in a watertight container or wrapping should be located near each enclosure.
- Enclosures should be safety green, either by painting or by having the color in the material, such as fiberglass or ABS plastic, for maximum contrast with other parts of the facility.

USING THE SHOWER

In principle, operating a safety shower should be very simple and should require no training. Anyone who is contaminated with a corrosive chemical should be able to wash that chemical off without having to read instructions or without having had prior training. Nevertheless workers should receive basic training regarding the use of the shower. Issues to consider include the following:

- Contaminated clothing should be removed.
- The affected person should stay in the shower for at least 15 minutes.
- The operators in the control room should know what to do when the alarm sounds.

INSPECTION

The ANSI standard calls for testing once a week. The test should cover the following issues:

- The water should flow at the prescribed rate.
- The water should be at a comfortable temperature.
- The alarm lights and alarms should work as designed.

- The water flow should stop properly when the handle is in the off position—the system should not leak or drip.
- The water should drain away properly.
- Ancillary facilities, such as the modesty curtains, should be in place, and they should be working properly.
- When the shower valve is opened, water should start flowing within 1 second. Also, the valve should stay open when the person takes their hands off it.

EYEWASH UNITS

Most safety showers include an eyewash unit. In some locations, such as laboratories, it may be sufficient to have an eyewash unit without a safety shower. The spray heads should be covered so that they are not contaminated. The covers should automatically lift off if the eyewash is activated.

When there is only a temporary need for an eyewash unit (such as at construction site), portable units can be used as long as they have sufficient capacity. Eyewash bottles are not recommended because of their limited supply of water.

CHAPTER

Siting and layout

11

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00011-1

INTRODUCTION

This chapter discusses the siting of a facility and the layout of equipment, piping, and buildings at that facility. (Information to do with the layout of firewater systems is provided in Chapter 9.)

The words "siting" and "layout" are often used interchangeably, but, strictly speaking, they have different meanings. Siting is concerned with the location of a facility. For example, if a company is planning on building a new chemical plant, management may consider sites in Texas, Mexico, or China. Layout, however, is to do with the manner in which equipment, piping, and buildings are placed at the process facility, and how they interconnect with one another. Most layout decisions will be made during the design phase, but some of the topics discussed here cover operations and maintenance also.

REGULATIONS AND STANDARDS

The following regulations and standards apply to siting and layout decisions:

- API RP 752—Management of Hazards Associated with Location of Process Plant Buildings.

  This standard provides guidance for managing the risk from explosions, fires, and toxic material releases to onsite personnel located in occupied buildings for onshore facilities, including refineries, petrochemical and chemical plants, and natural gas liquids extraction and liquefaction plants. Tents and other soft-sided structures are not covered.

  The standard was significantly upgraded following the Texas City explosion (2005). It also incorporates comments from OSHA (including citations from their National Emphasis Program) and lessons learned from other explosions.

  The meaning of the word "occupancy" is open to some interpretation. Low occupancy buildings such as those used for analyzers and that will never be permanently occupied are excluded.

  RP 752 describes three approaches that owner/operators may use to conduct a facility siting evaluation:
- A "consequence-based" approach that takes into consideration the impact of explosions, fires, and toxic releases based on "maximum credible events" for each building and type of hazard considered.
- A "risk-based" approach that is quantitative and takes into consideration numerical values for both consequences and frequencies of those catastrophic events.
- A "spacing table" approach (fires only) uses experience-based tables that specify the minimum required separation distances between equipment and occupied buildings.

The standard outlines the following three-stage analysis process for identifying hazards and managing risk to building occupants from fires, toxic releases, and explosions.

- During Stage 1, the study team identifies each building at the facility, verifies potential hazards, and screens out buildings based on occupancy levels and function during an emergency.
- In Stage 2, the buildings that met the previous screening criteria are evaluated with consequence modeling for vapor cloud explosion and toxic release hazards. If the team determines that a building(s) has a sufficient hazard, then a Stage 3 is justified.
- During the Stage 3, the study team identifies and analyzes the frequency of potential scenarios, either qualitatively or quantitatively. Recommendations are then developed to mitigate the risks where appropriate.
- API RP 753—Management of Hazards Associated with Location of Process Plant Portable Buildings.
- NFPA 59A—*Siting of Liquefied Natural Gas Facilities*.
- NFPA 20—Standard for the Installation of Stationary Pumps for Fire Protection.
- NFPA 24—Standard for the Installation of Private Fire Service Mains and their Appurtenances.

SITING

The selection of a site requires consideration of many nontechnical issues such as government incentives, financing, local regulations, the availability of feedstocks, the quality of the local work force, the location of the market, and the potential for severe weather.

Since such siting choices are made only rarely the word "siting" in this chapter also includes decisions to do with the layout of major operating units within a facility. For example, in an oil refinery, the relative locations of units such as the Cat Cracker, Alkylation, and Boiler House can be considered to be siting issues. Once their location has been decided upon, then layout decisions are made with respect to individual equipment items such as distillation columns, heat exchangers, and fired heaters. Regardless of which word is used, many of the issues discussed in this section apply equally well to both.

Attention should be given to the potential for floods, snowfall, wind severity, and earthquakes in the area. Site selection should also consider availability of closeness to raw materials and to customers, access roads, municipal fire protection, water supply, and distance from the local community.

The likelihood of future expansion of any major process unit should be considered in the layout decisions. The minimum spacing between units should not be viewed as a location for future expansions.

The following checklist questions provide guidance to do with siting:

- Can the unit be located to minimize the need for offsite or intrasite transportation of hazardous materials?

- What hazards does the unit at this site pose to the public or workers in adjacent units, offices, or maintenance areas? Consider the following:
  - Vapor clouds of toxic materials
  - Thermal radiation from fires and flares
  - Overpressure from explosions
  - Contamination from spills or runoff
  - Noise
  - Contamination of utilities such as breathing air, potable water, or sewers
  - Impacts from items such as train derailments or turbine blade fragments
- Consider the same issues with regard to existing units affecting the proposed site.
- Are there existing ditches or trenches where inert, toxic, or flammable vapors could accumulate?
- Consider external forces, including the following:
  - High winds
  - Earthquakes and tsunamis
  - Other earth movements such as sink holes, landslides, freeze/thaw heaving, coastal erosion, and settling
  - External utility failures
  - Fog
  - Airborne particulates
  - Natural fires
  - Extreme temperatures
  - Flooding
  - Lightning
  - Drought
- Expansion or modification plans.
- Can the unit be built without lifting heavy items over operating equipment and piping?
- Traffic and roads.
- Are there suitable barricades between process equipment and adjacent roadways?
- Is vehicular traffic restricted where pedestrians are present?
- Are overhead pipe racks protected from crane impacts?
- Is there adequate access for emergency vehicles?
- Could access roads be blocked by trains, congestion, or construction equipment?
- Are access roads designed to eliminate sharp curves?

LAYOUT

The following comments and guidance apply to the layout of process facilities:

- Process flow generally dictates the layout of equipment within an operating unit.

- Highly hazardous areas should be separated from low hazard areas. High hazard areas are those that meet one or more of the following criteria:
  - Contain flammable liquids at a pressure of 35 bar or greater
  - Contain combustible liquids at a temperature above their flash point
  - Contain LPG, butane, hydrogen, ethylene, and acetylene at any pressure
  - Contain highly reactive or toxic compounds such as hydrofluoric acid or anhydrous ammonia
- The facility or plant site should be level. If this is not possible sloped topography can be used to achieve additional design safety. For example, major storage facilities should be located at a lower elevation than the process area to prevent released liquid or heavy hydrocarbon vapors from flowing downhill to the process area.
- Prevailing wind should be considered when locating ignition sources such as fired heaters and flares. Areas with high concentrations of personnel, such as office buildings, shop areas, and existing neighboring community areas, should also be considered—in reference to prevailing wind—to reduce exposure from flammable materials, high-pressure sources, and toxics.
- The likelihood of future expansion of any major process unit should be considered in the layout decisions. The minimum spacing between units should not be viewed as a location for future expansions.
- Spacing between major process units should be 25 meters or more. Spacing greater than 60 meters, except for specialized operations such as emergency flares, provides little decrease in risk and may actually increase the overall hazard because piping runs will increase in length.
- The drainage system should remove spilled liquids to a safe location with minimal exposure to piping and equipment.
- Good access should be provided for normal operations, emergency response, and escape and evacuation. In particular, there should be direct, unobstructed accessways that are continuous from one end of the unit to the other and that are connected to roads surrounding the unit.
- Continuous ignition sources should be located away from probable points of release of flammable materials. In particular, pumps and compressors, which are the most likely source of accidental leaks, should be located at least 15 meters from sources of ignition such as fired heaters and internal combustion engines.
- Fire hoses must be able to reach any area that could be affected by a fire or chemical release.
- Air intakes should be located away from potential releases of combustible or toxic vapors.
- When operating conditions necessitate locating adjacent pieces of equipment closer than desirable from a fire protection standpoint, such as is often found on offshore platforms, additional fire protection measures should be considered.

- There should be separation of the facility from persons and property beyond adjacent property lines.
- The site must be secure from potential attackers.

Once safety and environmental issues have been addressed, equipment spacing should be organized so as to minimize the expense of the intermediate piping and valving, particularly when expensive alloys are being used.

Highly hazardous areas in a facility should be separated from low hazard areas. High hazard facilities can be considered to be those that meet one or more of the following criteria:

- Contain flammable liquids at a pressure of 35 bar or greater
- Contain combustible liquids at a temperature above their flash point
- Contain LPG, butane, hydrogen, ethylene, and acetylene at any pressure
- Contain highly reactive or toxic compounds such as hydrofluoric acid or anhydrous ammonia

SPACING

Table 11.1 provides some general guidance for the minimum spacing between onshore equipment items. Actual distances will be adjusted according to local codes, company standards, area classification, and the findings of hazards analyses. Table 11.2 provides similar guidance for items located in the field.

The guidance provided above may be modified (in either direction) by the following factors:

- The term “buildings” refers to those structures that are normally occupied. If a building is not normally occupied, then it may be possible to reduce the spacing requirements.
- If equipment, tanks, or piping contains highly hazardous chemicals, the spacing requirements may increase.
- The presence of passive fire protection may reduce spacing requirements.
- If vehicles are present, spacing requirements may have to be modified.
- Flare spacing will be developed based on radiation studies.
- Tanks that are gas-blanketed may require additional spacing.

PROCESS EQUIPMENT

- Towers and vessels should be spaced at least 3 meters from unit pipe racks.
- Reduced spacing is permitted only when adequate access for firefighting and maintenance can be maintained.
- Towers and vessels should be located at least 30 meters from fired heaters or fired reboilers.

Table 11.1 Suggested Minimum Spacing for Onshore Equipment Items (Meters)

Air Fin Coolers	X																		
Main Buildings	15	X																	
Boilers	30		X																
Compressors (Motor)	7.5	30	30	X															
Compressors (Turbine)	10.5	30		—	X														
Cooling Towers	30	30	45	30	30	X													
Electrical Buildings	15	.5	15	15		30	X												
Fired Equipment	30	30	15	30		30	15	X											
Firewater Pumps, Emergency Equipment	30	15	45	45	30	30	15	45	X										
Flares	—	—	—	—	—	—	—	—	—	X									
Heat Exchangers	3		30	15	20	30	15	30	45	—	X								
Pipe Racks	3	15	6	6	15	15	4.5	6	30	—	3	X							
Process Equipment	3	30	30	15	20	30	15	30	45	—	5	3	X						
Property Lines	45	30	45	45	45	30	30	45	45	—	45	45	45	X					
Pumps	7.5	30	30	15	20	30	15	30	45	—	3	3	3	30	X				
Storage Tanks (Water)	7.5	7.5	15	15	15	7.5	7.5	15	7.5	—	15	7.5	7.5	15	7.5	X			
Storage Tanks (Hydrocarbon)	45	60	45	45	45	45	45	45	60	—	60	15	45	60	45	45	X		
Storage Vessels (LPG)	60	60	60	60	60	75	45	60	75	—	60	45	60	100	60	30	30	X	
Loading Racks	45	60	45	60	45	60	45	45	45	—	45	15	45	45	15	15	45	45	X

Table 11.2 Suggested Minimum Spacing for Field Items (Meters)

Hydrocarbon Wellheads	—																			
Non-Hydrocarbon Wellheads	45	—																		
Process Equipment	45	30	—																	
Open Flame Equipment	60	45	45	—																
Natural Gas Engines	45	30		45	—															
Crude Condensate Pumps	45	30	7.5	45	22.5	—														
Water Pumps	30	—	3	30	—	—	—													
Steam Generator	45	30	45	45	45	45	30	—												
Storage Tanks (Hydrocarbon)	45	45	30	45	45	15	15	45	—											
Storage Tanks (Non-Hydrocarbon)	45	30	15		22.5	15	7.5	45	15	—										
Lube Oil Storage	45	30	15	30	7.5	15	—	30	30	15	—									
Truck Loading Connections	45	30	30	45	45	30		45		15		—								
Pits, Flares, Gas Vents	60	45	45	45	45	45	45	45	45	45	45	45	—							
Electrical Equipment	45	—	45	45	45	30	30	45	45	—	45	45	45	—						
Buildings	45	30	45	45	30	30	15	45	45			30	45	—	—					
Public Buildings	60	45	60	60	45	45	30	45	45	30	30	45	60	30	—	—				
Facility Line	—	—	—	—	—	—	—	—	—	15	—	—	—	—	—	—	—			
Roadway (Lease)	15	—	30	30	22.5	30	15	30	45		30	6	45	15	—	—	—	—		
Property Line	45	30	45	30	30	45	15	45	30	30	30	45	60	15	—	—	—	—	—	
Roadway (Public)	45	30	45	30	30	45	15	45	30	30	30	45	60	15	—	—	—	—	—	—

- Equipment integrated with major towers such as unfired reboilers, overhead exchangers, and feed effluent exchangers may be located closer to the fractionating column that they are associated with than is indicated in the spacing tables. However, access for firefighting and maintenance should be maintained.
- Vessels containing flammable or combustible liquids should not be located beneath pipe racks or air coolers.

PROPERTY LINES

- Adequate spacing is required between facilities and the property line to minimize exposure to others. The spacing also provides protection to the facility from development on adjacent property.
- Greater spacing should be considered if adjoining property contains process plants, large storage tanks, or other potential hazards.

BLOCKS AND ROADS

A large plant composed of several major units should be laid out in a rectangular or block pattern with adequate roadways giving access to all critical equipment items and for escape during an emergency. The streets that separate blocks are excellent fire breaks; they also facilitate the movement and use of firefighting equipment. Therefore, they should be kept clear. During an emergency, it may be necessary to block certain roadways or they may themselves be blocked by debris; therefore, each unit should have two or more approaches and exits to allow for escape and to provide access for emergency equipment.

Tank farm roads may be narrow, but they should have all-weather capability and have turnouts at convenient intervals so that vehicles can move in either direction.

ROUTINE ACCESS AND EGRESS

For routine operations, the following layout features for routine access and egress should be considered:

- Walking/working surfaces should be designed to avoid slippery conditions and tripping hazards.
- Walkways should be free of obstructions.
- Equipment, valves, and instrumentation that are routinely used should be accessible from grade or a safe platform. Items accessed occasionally may be provided with a fixed vertical ladder.

- Access to equipment, such as compressors and pumps, should be provided to avoid stepping on piping or other appurtenances not specifically designed for that purpose.
- The spacing of equipment should consider maintenance access. Maintenance requirements are dependent on the size and type of mechanical equipment, transportation of equipment parts, as well as access requirements for tool and lifting clearances.
- Consideration is to be given to spacing and overhead clearance to permit the use of mobile equipment and power tools for equipment service and maintenance during operation and turnaround periods.

FIREFIGHTING ACCESS

- Where possible, primary fighting should be provided through fixed firefighting systems such as remotely operated hydrants/monitors and deluge systems.
- Access to process units/areas for firefighting and other emergencies should be provided.
- Designated walkways should have adequate vertical and horizontal clearance for emergency response personnel and their equipment.
- Access from two directions should be provided between integrated layout process units.
- Main accessways should be at least 6 meters wide, thus allowing them to act as a firebreak.
- Main accessways for firefighting should not be located under pipe racks and should not pass through adjacent units. They should be provided through process-unit areas at 60-meter minimum intervals to allow firefighting from two directions with 30-meter hose lengths.
- Secondary accessways should be 3.6 meters wide for access by firefighters dragging hose or 6 meters wide with 4.5 meters height clearance to permit access by mobile firefighting equipment. Secondary accessways may pass under pipe racks, provided clearance is adequate. Alternate secondary accessways are necessary to prevent entrapment of firefighters if flammable vapors are present; a fire flares out of control, or the wind changes.

HAZARDOUS CHEMICAL AREAS

Areas where a worker could come into contact with hazardous chemicals should be marked with a yellow line or barrier. No one is allowed to cross that line unless they are wearing the correct protective equipment, usually goggles and chemical-resistant clothing. A faceshield and special boots may also be required.

The designated area should be identified by a yellow line painted on the ground and a yellow plastic chain fence (this should have weak links so that workers or emergency responders can break it during an emergency).

SECONDARY CONTAINMENT

Secondary containment generally consists of a containment or bund wall around equipment or tanks containing large volumes of liquid. If the equipment leaks or the tank is overfilled, the liquid is contained and thus prevented from flowing into other parts of the facility, where it could create a safety and environmental problem.

Such a system, which is illustrated in Figure 11.1, is totally passive and therefore inherently safe. It does not require instrumentation to respond, nor is human intervention required.

The general rule is that the secondary containment should have a volume equal or greater to 110% of the volume of the largest tank being protected. If multiple tanks are enclosed, then only a spill from one tank needs be considered.

Although a system such as that shown in Figure 11.1 is inherently safe, the drain valve in the wall has to be checked. It is needed because it will be necessary to drain rainwater from the contained area. But if the valve is left open or if the drain line is broken, say by a passing vehicle or by someone treading on it, then the secondary containment will be nullified.

DRAINAGE

Drains can create a common cause failure by allowing different types of liquid to mix with one another thus creating the possibility of an unforeseen chemical reaction; they can transport hazardous materials from one location to another, and, if air is mixed with any hydrocarbon vapors in the drain, an explosive mixture can be created. Also drains can overflow, thus leading to the possibility of hazardous chemicals entering locations where they are not expected. To minimize potential problems with drains, it is suggested that the following guidelines be followed:

- Surface drainage should enter storm drains, not process drains.
- Process or oily-water drains should not be located near living quarters or control rooms.

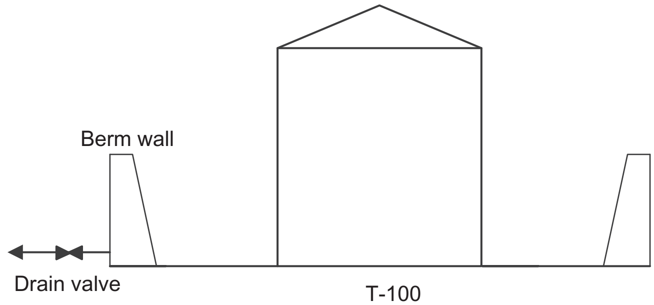

FIGURE 11.1

Secondary containment.

- The drain system should slope away from storage areas and have sufficient capacity to handle large volumes of firewater.

EQUIPMENT

Major equipment items, and the process flows from one item to another, will determine many of the decisions to do with layout.

Process flow generally dictates the layout of equipment within an operating unit. In general spacing between major process units should not be less than 25 meters. The spacing between individual pieces of equipment is determined by operational access requirements and fire protection. Mechanical equipment items, particularly pumps and compressors, are the most likely source of accidental leakage. Hence they should be located at least 15 meters from sources of ignition such as fired heaters and internal combustion engines. Spacing greater than 60 meters, except for specialized operations such as emergency flares, provides little decrease in risk and may actually increase the overall hazard because piping runs will increase in length. Where operating conditions necessitate locating adjacent pieces of equipment closer than desirable from a fire protection standpoint, such as is often found on offshore platforms, additional fire protection measures should be considered.

Some companies use lookup tables that provide minimum acceptable distances between different types of equipment. Kern (1977, 1978) provides guidance to do with the spacing of pumps, compressors, and process furnaces.

Once safety and environmental issues have been addressed, equipment spacing should be organized so as to minimize the expense of the intermediate piping and valving, particularly when expensive alloys are being used. Fire hoses must be able to reach any area that could be affected by a fire or chemical release.

The following sections provide guidelines to do with the layout of various types of equipment.

VESSELS

- To the extent practical, large vessels should be located where they do not block major explosion venting paths.
- For initial layout development planning a space of about 1—1.5 meters around vessel footprints should be reserved for instruments, piping, access, and visual inspection. This may change once piping sizes and requirements are known.
- If possible, pressure storage vessels in flammable material service should be located downgrade and downwind from any continuous ignition sources such as fired heaters.
- Pressure storage vessels should not be located within buildings, or within the spill containment systems (diked enclosures or remote retention basins) of other storage.

- Vessels should be located to permit maximum dissipation of vapors by free circulation of air.
- Ground contours and other obstacles should be taken into account for their effects on air circulation.
- Single horizontal storage vessels should have at least one side accessible from a road- or accessway. Grouped horizontal storage vessels should have at least one side of the area defined by the group accessible from a road- or accessway so as to provide access for firefighting equipment.
- Horizontal vessels should be oriented so that their longitudinal axes do not point toward other containers, process equipment, control rooms, loading facilities, or flammable or combustible liquid storage facilities.
- Horizontal vessels within the same group, regardless of fireproofing, should be arranged longitudinally, side by side. Head to head arrangement should not be used for grouped vessels.
- Offshore, horizontal vessels handling hydrocarbons should be oriented such that their heads point toward the open sides of the platform to protect the integrity of fire and blast walls.

Table 11.3 provides guidance to do with spacing around process vessels.

- When spacing is expressed in terms of vessel diameter, the diameter of the largest vessel is used.
- For a group of drums, use the combined volume of drums in the group.
- Distance from boundary line or facility to centerline of peripheral dike wall surrounding the storage vessel should not be less than 30 meters at any point.
- If spill containment is by the use of dikes, the edge of the spill containment area is defined as the centerline of the dike. If spill containment is by a remote retention basin, the edge of the spill containment area is defined as the outer edge of the wetted area containing the design quantity of spilled liquid.

PUMPS

Table 11.4 provides guidance on pump spacing.

The following guidelines should be considered with regard to the layout of pumps.

- Pumps are frequent sources of leakage and should therefore be located as far as practical from continuous sources of ignition. They should not be located beneath other equipment, such as vessels, air fin coolers, or pipe racks, in order to avoid fire involvement of such equipment.
- Pumps handling hydrocarbons should be at least 15 meters from furnaces, thermal oxidizers, internal combustion engineers, and other sources of ignition.
- Pumps should be at least 1.5 meters from one another.

Table 11.3 Minimum Spacing Between Aboveground Pressure Vessels

Boundary	**Minimum Horizontal Spacing to Spheres and Drums**	
Between any two spheres	¾ sphere diameter but not less than 15 meters	
Between shells of any two horizontal vessels	One shell diameter but not less than 1.5 meters	
Between a sphere and a drum	The larger of ¾ sphere diameter or one horizontal vessel diameter	
Between two groups of horizontal vessels	15 meters	
Property lines adjacent to land which is developed or could be built upon, public highways, main line railroads, and manifolds located on marine piers and building of high occupancy (offices, shops, labs, warehouses, etc.)	**Capacity per vessel (m^3)**	**Minimum spacing (meters)**
	8–110	15
	110–260	25
Note: Where residences, public buildings, places of assembly, or industrial sites are located on adjacent property, greater distances should be considered.	>70–90	30
	>90 (340)–120 (450)	40
	>120 (450)–200 (760)	60
	>200 (760)–1,000 (3,800)	90
	> 1,000 (3,800)	120
Nearest process equipment in onsite unit or utility plant (or nearest unit limits if firm layout is not available)	60	
Flare or other equipment containing exposed flame	60	
Refrigerated storage facilities	¾ tank diameter but not less than 30 meters. Need not exceed 60 meters	
Atmospheric storage tanks containing flammable liquids	1 tank diameter but not less than 30 meters; need not exceed 60 meters	
Atmospheric storage tanks containing combustible liquids	½ tank diameter but not less than 30 meters; need not exceed 60 meters	
Edge of spill containment area for refrigerated, flammable, or combustible liquid storage tanks	15	
Edge of remotely located retention basin	15	

- Pumps should be at least 3 meters from equipment handling flammable materials.
- Pumps should, where possible, be located along the outer edge of the plot limit, outboard of columns and vessels, and with no equipment installed overhead. If it is necessary to locate pumps alongside in-plant overhead pipeways, the process ends should be at least 3 meters outside the extremities of the overhead pipeway.

Table 11.4 Pump Spacing to Fireproofed Pipe Racks and Air Coolers

Pump Type	Pump Fire Protection	Recommended Spacing to Pipeways and Air Coolers
Pumps handling combustible liquids at temperatures below their flash points.		Adjacent to but not under
Pumps handling flammable liquids (or combustible liquids at temperatures above their flash points)	Without water-spray systems Equipped with water-spray systems	3 meters Adjacent to but not under
Pumps handling flammable or combustible liquids at temperatures above their autoignition temperatures	Without water-spray systems Equipped with water-spray systems	4.5 meters 3 meters
Pumps handling flammable liquids (or combustible liquids at temperatures above their flash points) at discharge pressures over 34.5 bar	Without water-spray systems Equipped with water-spray systems	4.5 meters 3 meters

- Pumps should not be located adjacent to critical, high-value equipment, under or adjacent to overhead fin fan coolers, or under main instrumentation and electrical cable runs.
- Pumps should be located without overhead obstruction to allow for removal.
- Normal operating temperatures of fluids handled by pumps should be used to determine if the fluids are considered combustible, flammable, or above auto-ignition. Any combustible fluid heated above its flash point should be considered a flammable liquid.
- On all process pumps, suction and discharge piping should be arranged to provide easy access to the pumps and associated equipment to eliminate such hazards as tripping or inadequate headroom.
- When locating pumps, special consideration should be given to high-pressure and high-temperature pumps.
- Pumps handling hydrocarbons above autoignition or 260°C should be grouped together and should be located at least 4.5 meters from other pumps handling hydrocarbons.
- Pumps handling flammable liquids at pressures above 34.5 bar should be grouped together and located at least 4.5 meters from other pumps handling hydrocarbons.
- Spacing between pumps handling flammable or combustible liquids and pipe racks that have not been fireproofed should be at least 9 meters.

HYDROCARBON STORAGE TANKS

The following guidance applies to hydrocarbon storage tanks, sometimes referred to as "API Tanks":

- Tank farm should be located at a lower elevation than process areas. Then, if one of the tanks leaks and the secondary containment are not effective, flammable and toxic materials will not flow into the process areas. (The same argument holds if the spilled liquid could create a vapor that is denser than air and that could then flow downhill.)
- Where it is not feasible to locate tank farms at elevations lower than process areas, increased fire protection measures may be required to offset the increased potential for ignition. These measures may include all or some of the following:
  - Diversion diking
  - High-capacity drainage systems
  - Vapor detection placed near potential release points
  - Increased fire protection systems such as foam, fixed water sprays, or similar protection measures
- Spacing between tanks should be great enough to contain the fire, prevent spread of the fire to other tanks, and to allow sufficient access for firefighting crews.
- Equipment other than associated piping should not be located within the diked area of storage vessels.
- If possible, do not locate uphill from a process area, other critical facility, or populated area to prevent released liquids and heavy hydrocarbon vapors from gravitating downhill into these areas.
- Equipment other than associated piping should not be located within diked areas of storage vessels.
- Spheres should be arranged in rows not more than two deep.
- At least one hemisphere of every sphere should be adjacent to a road- or accessway to provide access for firefighting.
- Flammable gas detection is not usually required for open tank areas unless the potential for gas accumulation has been identified. (Storage tanks at upstream facilities usually contain stabilized crude, nonvolatile combustible liquids.)
- Toxic gas detection should be installed if the potential exists for toxic gas accumulation in a tank area, or else entry into a bermed area must be treated as a confined space entry.
- Fire detectors should be provided for tanks containing combustible or flammable liquids. Linear heat detectors are the preferred fire detectors for large storage tanks.
- Methanol tanks should be provided with heat detectors, linear thermal detectors, or fusible/pneumatic loops.

COMPRESSORS/COMPRESSOR DRIVERS

- Gas compressors over 150 kW and expanders should be separated from other equipment as specified in the applicable spacing tables.
- Steam- or motor-driven gas compressors that are less than 150 kW should be treated the same as pumps in regard to spacing.
- All gas compressors should be located at least 15 meters away and, if practical, downwind from fired heaters.
- Equipment should not be located over gas compressors.
- Associated intercoolers, scrubbers, and so on may be located in the compressor area and need not comply with the listed spacing recommendations, but should provide clear access for firefighting and maintenance.
- Access for firefighting should be provided from at least two sides.
- Steam or motor drivers require spacing only for protection against adjacent risks or for operation and maintenance.
- All compressor engines and turbines should receive combustion air from outside the compressor building through filtered air intakes, which are located on the opposite side of the building from the process equipment. The air filters should preferably be located on the prevailing wind side of the building.
- Auxiliary burners for waste heat recovery units should be located at a minimum of 15 meters from the gas turbine-driven equipment.

HEAT EXCHANGERS

- Spacing should be sufficient to permit safe blinding and tube bundle removal without damage to or removal of adjacent piping or valves.
- Equipment should not be located above heat exchangers containing flammable or combustible liquids over 260°C.
- For initial layout development planning, a space of about 1–1.5 meters around heat exchanger footprints should be reserved for instruments, piping, access, and visual inspection. This may change once piping sizes and requirements are known.
- Sufficient clearance should be provided for removal of tube bundles from shell and tube heat exchangers for maintenance, inspection, or replacement.
- No equipment should be installed immediately under air-cooled heat exchangers other than equipment that is part of the exchanger system. Also, no equipment should impede the exhaust airstream above the exchanger.
- If the heat exchanger is handling a fluid which is over 315°C or the autoignition temperature, heat exchanger spacing should be increased to 4.5 meters.

AIR FIN COOLERS

- Vessels and/or pumps containing flammable or combustible liquids should not be located beneath air coolers.

- Heat exchangers containing hydrocarbons over 260°C should not be located beneath air coolers.
- Air coolers should be spaced 15 meters from positive ignition sources such as fired heaters.
- When the air cooler is located above a process-unit pipe rack, the clearance between the lowest portion of an air cooler and the uppermost pipe should be 2.5 meters minimum.
- Flanges and valves in hydrocarbon pipelines should be minimized beneath an air cooler.
- Multiple flanges and valves, such as in control stations, should not be located under air coolers.
- Equipment should not be located above air coolers.
- Air discharges should not create operational and maintenance problems for other equipment.

BOILERS AND STEAM GENERATORS

- Boilers and utility equipment should be spaced to prevent exposure to fire or explosion damage. Fuel-oil day tanks, fuel-oil pumps, and heat exchangers should be spaced 9 meters away from other utility equipment.
- Fired steam generators should be located 30 meters minimum from process equipment handling flammable and combustible liquids and gases.
- Waste heat steam generators that have supplemental firing and are part of a process unit should be spaced in accordance with requirements for fired heaters.
- Within the utility plant area: control rooms, feedwater pumps, deaerators, and similar equipment may be spaced in accordance with good engineering practices to provide adequate spacing for operation and maintenance.

COOLING TOWERS

In spite of the fact that they handle large quantities of water, cooling towers can be a fire hazard. For example, if a heat exchanger tube leaks and the pressure of the process stream are greater than that of the cooling water, then hydrocarbons can enter the cooling water. When they reach the cooling tower, the hydrocarbons will be vaporized. If they find a source of ignition, the cooling tower could be set on fire. For this reason, it is good practice to install a hydrocarbon detector in the vapor space above the cooling tower. This will warn of a leak somewhere in the system.

The following additional guidance is provided with regard to the design and operation of cooling towers:

- They should be located at least 30 meters from process equipment.
- Where possible, cooling towers should be downwind from substations, pipe racks, and process equipment so that fog developed will not cause corrosion or obstruct vision.

- If a heat exchanger has process fluid on one side and lower pressure cooling water on the other a tube leak will cause hydrocarbons or toxic chemicals to enter the cooling tower. This can lead to a fire at the tower or the widespread dispersion of the toxic materials.

FIRED EQUIPMENT

Fired equipment contains one or more open flames. If hydrocarbon vapors come into contact with the flame, a fire or explosion could result. The following issues should be considered with regard to the location of fired equipment:

- Fired heaters are a continuous ignition source and should be separated by at least 15 meters from process equipment containing flammable liquids.
- The prevailing wind direction should be considered when locating fired heaters to minimize the potential of igniting vapors. Where practical, they should be located on the upwind side of the facility.
- Locate fired heaters at least 15 meters from pumps, compressors, and vents that might release ignitable vapors.
- The spacing should be increased to 22.5 meters where adjoining vessels will be entered for maintenance while a fired heater remains in operation.
- Fuel knockout drums should be spaced as close as possible to their fired equipment, but no closer than 3 meters.
- The top of the exhaust stack should be at least 3 meters higher than the equipment within 15 meters and 6 meters higher than any working platform/walkway within 60 meters.
- Diesel engines, gasoline engines, and combustion gas turbines present a constant source of ignition for possible hydrocarbon releases and should be carefully located. Such equipment should be insulated or otherwise isolated by passive systems to maintain a low outer surface temperature.
- A minimum separation of 10.5 meters should be provided between high skin temperature equipment and equipment handling hydrocarbons below auto-ignition temperature or below 260°C.
- Equipment with skin temperatures in excess of 70°C should not be located less than 2 meters above walking/working surfaces.

EQUIPMENT STACKING

It may be necessary to stack equipment when space is limited. However, it is important to understand that doing so is likely to make fires more dangerous and the fighting of those fires more difficult. The following general guidance should be considered:

- No more than three levels of stacking should be allowed.
- Equipment should not be located over pumps or compressors handling flammable materials or over air fin heat exchangers.
- It must be possible for firefighters to access all equipment.

AIR INTAKES

The location of air intakes in relation to adjacent process equipment should be carefully selected by taking into account prevailing wind direction, probable horizontal and vertical vapor dispersion patterns, and the hazard that results from possible formation of a flammable vapor/air mixture.

Equipment and buildings that require protected air supplies include the following:

- Internal combustion engines and turbines
- Air compressors
- Inert gas generators
- Forced draft furnaces
- Electrical equipment boxes
- Occupied buildings
- Buildings that contain unclassified electrical equipment
- Boilers
- Breathing air compressors

The following general guidance can be followed:

- Air intakes at onshore facilities should be located at a minimum of 7.5 meters above grade when within 15 meters of process units or within 30 meters of process units containing flammable hydrocarbons. Calculation of air intake design should include an analysis of the effect of the intake on surrounding air patterns to ensure that airflow to the intake is above the 7.5 meters minimum level.
- When air intakes serve large internal combustion sources, such as gas turbines, special care should be taken in spotting the intake to avoid significant reduction in turbine efficiency.
- Where air-conditioning equipment is used for buildings within 150 meters of hydrocarbon processing plants, features such as flammable or toxic gas detection and heating, ventilation, and air-conditioning (HVAC) shutdown, in addition to the location of the air intake, should be considered in order to protect personnel and equipment in the building from toxic or flammable vapors.

PIPING AND VALVES

Although equipment types and the flow of process streams between the equipment types are the main drivers in plant layout, piping is also important—not least because it constitutes a major part of the overall cost of the complete facility.

The following general guidance should be considered with regard to the layout of piping and valves:

- Where vents and relief valves are piped to a closed system, the relief line should vent away from sources of ignition.
- Pig receivers should be oriented so that their access doors point away from other process equipment (overboard on an offshore platform).

- Manually operated emergency isolation valves, fire hydrants, and other emergency equipment should be accessible in worst-case scenarios (this may require placing them behind a screen or berm).
- Piping should be installed on aboveground pipeways whenever possible because they provide excellent separation between equipment items.
- Piping should not be located at grade level because it is difficult to keep clean, it is more subject to corrosion, and it obstructs free access and is difficult to monitor for external corrosion and leaks.
- Trenches should not be used for process piping because the flammable or toxic vapors may accumulate in them.
- Main pipe racks should be located outside of process-unit battery limits.
- Provide spacing from pipe racks to equipment for operation, maintenance, and to reduce involvement from adjacent fires. Process equipment should not be located under pipe racks.
- Piping which interconnects various process areas or which goes to storage should not be routed through plant areas that could be shut down independently for turnarounds.
- Above grade piping should be consolidated into pipe racks and routed through the process area in such a manner as to offer minimum obstruction to firefighting and maintenance operations. Piping from other process area or offsite operating area should not be routed on onsite pipe racks unless they terminate at the process unit served by the onsite pipe rack.
- Pipe racks should be located outside of areas enclosed by spill retention walls/berms.
- Lateral pipe racks with interconnection to pipe racks parallel to accessways should be at least 24 meters apart if the laterals cross the accessways. This provides space for raising and lowering crane booms.
- The area under pipe racks should be kept clear for firefighting and other access and should not be encroached upon even though other equipment spacing standards might still be met.
- The distances listed in the spacing tables refer to the horizontal spacing between the edge of an overhead pipe rack and the nearest part of the pump (usually the stuffing box). If the pump is handling a fluid that is over 315°C or the autoignition temperature, this distance should be increased to 4.5 meters.
- There are no limitations on spacing pump drives from the pipe rack except those providing for access for mobile equipment.

UTILITIES

Most of the layout issues to do with utilities are similar to those already discussed. However, the following special considerations apply:

- It is likely that utility services will be needed during the emergency response. Therefore, units such as the boiler house should be located well away from process facilities so that they will not be exposed to fires and explosions originating in the process plants.

- Substations, switch rooms, and firewater pumps should be located in nonhazardous areas.
- Main distribution systems for water, steam, and electric power should be looped, with block valves (or disconnect switches on electric lines) at appropriate points so that, if any part of the system is damaged, supply can be obtained from another source.
- Branch lines should have block valves (or disconnects) near the point of takeoff from mains so that they can be isolated if ruptured or damaged.
- Electric power lines should not traverse areas where fires are likely to occur. A power line that is critical to safety should be buried.
- Lifting beams, crane, and fork lift truck access and laydown areas should be located so as to minimize lifting and swing load damage, particularly to equipment requiring regular maintenance or replacement. Spacing and access areas should be checked against the size and turning radii of various cranes and other equipment required for maintenance and shutdowns.

INSTRUMENTS AND CABLES

- Instruments, instrument leads, and critical power cables should be located so as to be protected during a fire. One means of reducing their exposure is to locate them on the upper levels of pipeways where they are shielded by process piping below. However, critical power and instrumentation cables should be protected using one or more of the following methods:
  - Route cables outside the fire hazardous areas
  - Use fire-resistant cables
  - Bury or fireproof instrument conduits

ELECTRICAL SUBSTATIONS

- Main and multiunit substations should not be part of administration buildings, shops, control buildings, laboratories, or any other nonrelated structure. In locations where it is deemed absolutely necessary to combine a main or multiunit substation with another structure, the substation should be separated by a 3-hour rated firewall with no direct access or any other penetration through the wall.
- Substations should be evaluated for blast-resistant construction and/or be located in an area where blast-resistant construction is not required. Depending on the location blast-resistant construction may be required to protect against a blast that could destroy the substation and adversely affect a safe shutdown of the unit(s) it serves.
- The preferred location for a main substation is as close to the property line as security permits.

- Main substations should be located in nonclassified locations that are free of cooling tower spray and other gases or vapors that could contribute to insulation and equipment failures. These substations should also be sufficiently removed from heat sources that could affect equipment capabilities.
- Spacing between critical electrical switch racks (switch racks associated with shutdown or emergency actions on process equipment) and equipment handling hydrocarbons should be 6 meters minimum, except that 15 meters of spacing should be provided between critical electrical switch racks and fired heaters or gas compressors.
- Noncritical switch racks should meet electrical classification criteria for spacing.

BARE-WIRE ELECTRIC POWER LINES

Bare-wire electric power lines should not be used in new construction. Where equipment is to be added to existing plants with bare-power lines, the guidelines given below should be considered.

- Bare-wire electric power lines should not be located directly below any permanent structure other than power line support structures.
- Clearance distances are provided by NFPA 70.
- In general, a distance of 15 meters should be provided between a bare-power line and process units. This provides space for maintenance and will protect the building were the line to fall.

BUILDINGS

The previous sections have discussed asset integrity issues to do with operating equipment and utility systems. Guidance regarding buildings and storage is provided below.

General guidelines regarding the location of buildings are as follows:

- Central control rooms should be located at a safe distance from the operating units, or they should be blast resistant or partially buried.
- Warehouses should also be located away from operating units. Not only do they have no blast resistance but the persons who work in them are less likely to be trained in emergency response than operators working in a control room.
- Combustion air and HVAC air intake points should be located so as to avoid gas or smoke ingress, and should be located as far as possible from exhaust ducts.
- Offices, administrative buildings, and parking areas should be located away from hazardous areas and product handling areas. These buildings, along with

greenbelts and planted areas, serve as buffers between the process plants and the public.

- A fire break free of from combustible vegetation should be maintained around the buildings.
- Spacing between buildings (other than process-unit structures), such as shops, laboratories, administration, should be based on the type of construction. Spacing should conform to the requirements of applicable NFPA codes, local fire codes, or the specifications in the spacing tables, whichever is more stringent.
- Spacing recommendations to main pipeways are based on all welded pipe in the pipeway. Sections of the pipeway containing numerous flanges, vents, drains, or other release sources should be treated as process area pipeways in regard to spacing.

Greater distances may be required where facilities are of very large size or contain high pressures or toxic materials. Where spacing is significantly below recommended distances, additional risk control measures are needed. These may include through the use of additional fireproofing, fixed water sprays, additional firefighting equipment, and fire or blast walls.

Ignition of gas clouds in confined spaces can lead to detonation-type explosions which are significantly more severe than open-air deflagrations:

- Flammable gas detection should be provided in all buildings containing high or low leak potential equipment.
- In enclosed areas containing flammable gas compressors, the minimum number of sensors is one per compressor unit, plus an additional sensor per three units or part thereof.
- Flammable gas detection should be by point or open path detectors located appropriately considering the potential development of hazardous gas clouds in the building.

Guidance to do with the layout of buildings is provided in API 752. This Recommended Practice outlines the following three-stage analysis process for identifying hazards and managing risk to building occupants from fires, toxic releases, and explosions.

- Stage 1—The study team identifies each building at the facility, verifies potential hazards, and screens out buildings based on occupancy levels and function during an emergency.
- Stage 2—The buildings that met the previous screening criteria are evaluated with consequence modeling for vapor cloud explosion and toxic release hazards. If the team determines that a building(s) has a sufficient hazard, then a Stage 3 is justified.
- Stage 3—Identify and analyze the frequency of potential scenarios, either qualitatively or quantitatively. Recommendations are then developed to mitigate the risks where appropriate.

OCCUPIED BUILDINGS

- Flammable gas detection should be provided in the HVAC inlet of any occupied building where release scenarios and dispersion modeling indicate potential gas concentration above ½ lower explosive limit (LEL). When dispersion results are not available, occupied buildings within 60 meters should include detection.
- Where gas is brought into a building for cooking or heating purposes, local flammable gas detection should be provided.
- Toxic gas detection should be provided in the HVAC inlet of any occupied building where release scenarios and dispersion modeling indicate potential gas concentration above the short-term exposure limit (STEL).
- Smoke detection should be provided in all occupied buildings on site, unless this is not compatible with the room's use. Where electrical equipment cabling is installed in floor or ceiling voids, smoke detectors should be located in these spaces, and in internal room spaces.

ELECTRICAL ROOMS/SUBSTATIONS

These rooms can act as ignition sources if located within an area where a gas cloud could develop.

- Flammable gas detection should be provided in the HVAC inlet of any pressurized electrical room or substation building where release scenarios and dispersion modeling indicate potential gas concentration above ½ LEL. When dispersion results are not available, such buildings within 60 meters of high or low leak potential equipment should include detection.
- If the building is not pressurized, flammable gas detection should be installed in the room. Point detectors are suggested.
- Smoke detection systems should be installed in all electrical and switch rooms. The detector location should take into account the HVAC system fitted to the room.
- Where electrical equipment cabling is installed in floor or ceiling voids, smoke detectors should be located in these spaces.

PRESSURIZED ENCLOSURES

- Flammable gas detectors should be provided in air intakes of ventilation systems for pressurized enclosures.
- Toxic gas detectors should be provided in air intakes of ventilation systems for pressurized enclosures where dispersion modeling indicates that toxic gas could generate hazardous concentrations at the HVAC inlet prior to a flammable hazard being generated.
- Smoke detectors should be installed in air intakes for pressurized enclosures.

PROCESS BUILDINGS

Process buildings contain hydrocarbons or toxic chemicals. Examples include analyzer buildings, metering stations, pump houses, and compressor stations.

Process buildings should be of noncombustible construction and they should have openings on all sides whenever practical to allow for ventilation and access by firefighting teams. If they must be fully enclosed (usually for protection against the weather), then ventilation should be provided to prevent the accumulation of flammable gases. The building exhaust vents should be located to preclude the accumulation of gases at low points such as pipe trenches. Fixed fire suppression systems should be installed in buildings containing high-value or critical equipment, such as generators, compressors, or gas turbines.

In order to declassify the interior of a building (such as control rooms, living quarters, or labs) that is inside a classified area, the occupied space must be purged and pressurized. A general rule is that there should be at least 12 air changes per hour.

TEMPORARY BUILDINGS

Temporary prefabricated buildings, including trailers, are used extensively for construction offices, temporary office space, storage space, and laboratories. These buildings are usually of light, wood frame construction. They come in standard sizes to allow easy highway transport and can usually be connected to one another to make multiwidth buildings. To avoid these types of buildings becoming permanent, there should be a date agreed on for their removal.

All of the people who died in the 2005 Texas City explosion were working in temporary buildings that were located adjacent to process equipment. Following that event, a much stricter attitude to the use of such buildings became industry wide.

Because of their light, combustible construction, these buildings should be placed at least twice the distance from an operating plant as a conventional control building. However, separation between them need not exceed around 60 meters.

It may be acceptable (if agreed to by the operating management) to place a trailer in a processing unit during shutdown if all of the following conditions are met:

- It is placed in the plant after the plant is shut down.
- It is removed before plant start-up.
- It meets minimum spacing distances from any other operating plant.
- A fire break of at least 10 meters is cleared around the building.

In addition, the following general guidelines should be considered:

- Provide at least one dry chemical or 10 liter pressurized water extinguisher for every 500 square meters and limit travel distance to any extinguisher to 20 meters.

- Provide skirts around elevated portable buildings to prevent accumulation of combustible materials underneath them.
- If computers are present in the trailers, a CO_2 fire extinguisher must be provided.

Temporary buildings and trailers should not be located to block access and egress routes, nor should they change vehicle movement patterns. Temporary buildings and trailers should not be located where personnel frequently have or will choose to traverse through high hazard areas in order to access the structures. Emergency routes should not be impeded or blocked by the location of the temporary facilities, and emergency response plans must be updated to include mustering and emergency response procedures whenever temporary buildings are added to a facility.

CONTROL BUILDINGS

In the event of a large explosion or fire, it is critical that control buildings (also called control rooms or control houses) are not seriously damaged. Not only must the people in them be protected, but it is important that the operators be able to take the appropriate emergency response actions, including the following:

- Shut down units adjacent to the emergency.
- Communicate by radio and speaker system with workers in the field. They will instruct these workers as to what has happened and what they need to do.
- Coordinate with outside emergency services, company headquarters, and regulatory agencies.

The following guidance should be considered during the design and construction of control buildings:

- Process-unit control houses should be located at the periphery of the process unit.
- The structural members and the interior and exterior walls of control buildings should be constructed of noncombustible materials.
- The exterior walls should be blast-resistant.
- Wall coverings, wood paneling, and trim should not be used because they contribute to the combustible fuel load.
- Doors should be constructed of noncombustible materials.
- Control rooms in plants handling flammable liquids or dust should not have windows.
- Furnishings should be noncombustible.
- Different functional areas in a control building (e.g., offices and the control room proper) should be separated by fire-resistant walls that extend from the floor to the roof.
- The control building foundation site should be higher than the surrounding areas so that a spill or surface drainage flows away from the control building

and does not block access. Alternatively, the control building can be partially buried.

- Positive, forced-air ventilation should be provided. The air intake should be taken from a safe, vapor-free location at least 10 meters above grade. If hydrogen sulfide, hydrocarbons, or other toxic or hazardous vapors could be drawn in by the air system, a vapor detection system should be provided. This system should alarm personnel in the control building at 20% lower flammable limit (LFL) and start 100% circulation at 60% LFL.

Guidance to do with control room layout is provided by Ottino (1991).

CONTROL LABORATORIES/ANALYZER BUILDINGS

Some facilities have control laboratories adjacent to the control room. These laboratories measure the composition of process streams. The samples can be either brought into the lab manually or there may be sample tubing from the process to the lab.

A 1-hour fire-resistant wall should separate the lab from the control areas. Entry into the lab should be through an outside door (there should be no doors between the lab and the control room). If a window between the lab and the control room is needed, it should be of wired glass, set in a steel frame, and be as small as possible.

Control labs should have at least one CO_2 fire extinguisher.

Analyzer buildings located within electrically classified areas should be provided with flammable gas detection.

WAREHOUSES

The following general guidance is provided to do with the design and operation of warehouses:

- General purpose warehouses are normally not classified. If flammable materials are transferred to or from containers, then that should be done in a separate classified area.
- No trucks should be allowed in warehouse areas containing highly flammable materials.
- Warehouses should also be located away from operating units. Warehouses have no blast resistance and the persons who work in them may not be trained in emergency response.
- Flammable and combustible liquids should be stored away from general-purpose warehouses, office buildings, and control rooms.
- The joins between walls and floors should be liquid tight.
- All doors and door openings should be fire resistant.
- Raised sills of at least 100 mm. should be provided at all door openings to prevent liquid flow to other areas.

- A ventilation system should be provided.
- Drainage should remove any spilled or burning liquid to a safe and environmentally acceptable location.
- Combustible building materials such as wood and fiberglass should not be used when hydrocarbons are present. The use of noncombustible building materials such as steel or concrete is preferred.

INSIDE STORAGE

The following general guidance should be followed with regard to storing materials inside buildings.

- Flammable and combustible liquids should be stored away from general-purpose warehouses, office buildings, and control rooms.
- The joins between walls and floors should be liquid tight.
- All doors and door openings should be fire resistant.
- Raised sills of at least 10 centimeters should be provided at all door openings to prevent liquid flow to other areas.
- A ventilation system should be provided.
- Drainage should remove any spilled or burning liquid to a safe and environmentally acceptable location.
- Combustible building materials such as wood and fiberglass should not be used when hydrocarbons are present. The use of noncombustible building materials such as steel or concrete is preferred.

OPERATOR SHELTERS

Operator shelters should be located at least 15 meters from the nearest process-unit equipment containing flammable liquids or vapors and 15 meters from fired heaters.

ELECTRICAL EQUIPMENT BUILDINGS

Electrical switchgear, circuit breakers, switches, and small transformers are normally grouped together in a building or Motor Control Center (MCC). Climate controlled buildings may also be required to house minicomputers, transducer banks, and other instrument interfaces. Putting this equipment in a building protects it from fires and explosions in the process area.

These buildings should preferably be located at the edge of the process area on the prevailing wind side of potential hydrocarbon or toxic releases to reduce the potential of these gases entering the building pressurization air intake. Also, the pressurization air intake should be located above grade.

Smoke detection systems should be installed in all electrical and switch rooms. The detector location should take into account the HVAC system fitted to the room.

NONPROCESS BUILDINGS

Offices, administrative buildings, and parking areas should be located away from hazardous areas and product handling areas. These buildings, along with greenbelts and planted areas, serve as buffers between the process plants and the public.

Fire detection by means of heat detectors should be installed in workshops.

LOADING AND UNLOADING

The loading and unloading of tank cars and tank trucks is hazardous for the following reasons:

1. Hoses are being routinely connected and disconnected
2. Moving vehicles are present
3. Workers are present—often very close to the hoses and moving vehicles

Therefore, special attention should be given to the layout of these areas, with particular consideration being given to the following issues:

- Truck loading racks for flammable and combustible liquids should be located near the plant gates to avoid truck traffic near process areas.
- LP-gas truck loading racks should be spaced 60 meters from process equipment, at least 45 meters from other types of truck loading racks.
- Tank car loading racks for flammable and combustible liquids should be located to avoid road blockage when spotting rail cars, ensuring passage for fire trucks or other service vehicles at all times.
- Loading racks handling low-flash material should be spaced at least 60 meters from process equipment handling hydrocarbons.
- Racks should be located so locomotives do not traverse within 15 meters of process-unit battery limits or tank storage.
- LP-gas tank car loading racks should be spaced 60 meters from process equipment and all tank storage and at least 30 meters from other types of tank car loading racks.

Similar concerns apply to wharves and piers where petroleum products and chemicals are being loaded and unloaded.

- Wharves handling flammable liquids should be spaced a minimum of 60 meters from process-unit equipment handling hydrocarbons.

- Wharves should be spaced at least 75 meters from fired heaters or other continuously exposed sources of ignition.
- Wharves handling LP-gas should be spaced at least 75 meters from other facilities and from wharves handling flammable liquids.

EMERGENCY EQUIPMENT

It is vital that emergency equipment be laid out so that it can be reached during an emergency. It should be accessible when fire, smoke, or toxic gases may be present.

PROCESS ISOLATION VALVES

- Isolation or battery limit valves should be installed in a safe, well-lighted, accessible location at the process-unit battery limits.
- The valves should be accessible from grade or from permanent fixed platforms equipped with stairway access.
- There should be access from two directions (such as stairways on both ends of platforms) when the isolation valves are in an overhead pipe rack.
- Valves should isolate the unit pipe rack and process unit from the main pipe rack and other process units.

EMERGENCY STATIONS

- Activation stations for emergency shutdown valves (ESDV) should be located at least 15 meters from the hazard the valve is intended to isolate.
- Water-spray valves and shutdown stations should be located so that they are at the battery limits in a well-lighted and easily accessible area.
- The water-spray control valve manifold should be located adjacent to the unit control room, where practical or in a location convenient to the operators.
- In freezing climates, the strainer, control valve manifold, and necessary system drains should either be located in a heated area within the control building, in a heated cubicle, or be insulated and heat traced.

HYDRANTS AND MONITORS

When possible, hydrants and monitors should be located such that they are capable of protecting two or more process units or tanks.

FIRE AND GAS DETECTION

It is vital that releases of flammable or toxic gases be detected as soon as possible so that the situation can be brought under control as soon as possible. Detection methods range from the use of sophisticated electronic equipment to simple human response. (A discussion to do with flammable and combustible materials and the definition of terms such as LFL is provided in Chapter 1.)

REGULATIONS AND STANDARDS

There are many regulations and standards to do with the layout of detection equipment. The following are representative:

- API RP 14C Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms
- API RP 500 Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1, and Division 2
- API RP 55 Recommended Practices for Oil and Gas Producing and Gas Processing Plant Operations Involving Hydrogen Sulfide
- ISA RP12.13 PT II Performance Requirements for Combustible Gas Detectors
- ISO 13702 Petroleum and Natural Gas Industries—Control and Mitigation of Fires and Explosions on Offshore Production Installations—Requirements and Guidelines
- NFPA 72 National Fire Alarm Code

LAYOUT OF DETECTORS

With regard to the layout of fire and gas detection devices, the following guidance should be considered:

- Point detectors should be located on a grid with a specified maximum spacing (5 meters is a value that is sometimes used).
- Open path detectors should be sited to maximize their coverage within the module. Hence they should be sited so as to avoid blocking the beam with equipment.
- Where the beams from open path detectors are parallel, they should not be more than 5 meters apart.
- Open path beams should be oriented horizontally in order to prevent the buildup of water on the transmitter/receiver unit.
- Point and open path detectors should be positioned appropriately for the density of gas that they are installed to detect. Detectors for gases whose density is less than that of air should be located at or above the expected point of release. Heavier than air gases and vapors sensors should be located at or below the expected point of release. (Consideration should be given to the fact that the expanding gas may cool down and become more dense.)
- Consideration should be given to prevailing winds, HVAC air circulation patterns, and effects from other equipment that could influence circulation.

Widely varying wind directions may warrant the installations of additional sensors.
- The dilution effect of air-conditioning and ventilation systems and to the effect of draughts should be considered.
- Flammable gas detectors should not be used to detect toxic gas and vice versa. Dedicated detectors should be installed.
- Gas detectors installed for the purposes of life-safety and/or asset protection should not be installed to detect fugitive emissions, such as might occur around the packing of a valve stem.
- The fire and gas detectors should be installed in locations accessible for calibration and maintenance but not in frequently used accessways.
- Placement of detectors should not interfere with process equipment maintenance.

Unless there is a probability of escalation, there is not generally a need to install dedicated dedicators around low probability leak sources. The following may be considered to be an exception:

- Small pipes and connections subject to failure due to vibration
- Manifolds with a large number of flanges
- Pipes subject to external corrosion
- Drain and sample points
- Control valves operating above 15 barg
- Areas containing a large number of small bore connections in a concentrated area

Open path detection should be provided around fixed ignition sources located within 30 meters of high or low leak potential equipment. Such open path detection should be located between the leak potential equipment and the ignition source and should shut down the affected unit on a confirmed gas signal.

Fire detection should be provided around high leak potential equipment. Fire detectors should be selected according to the type of fire expected.

RESPONSES

Each facility will need to develop standards as to how to respond to alarms. As a starting point, it is suggested that the fire detection system should provide two levels of alarm. The first level indicates that a fire has started, but either it is small and controllable or there may have been an alarm instrumentation failure. The second level of alarm indicates that the fire has been confirmed and that it is large enough to need an emergency response.

The following guidance is provided with setting the first level of alarm:

- Single ultraviolet/infrared (UV/IR) flame detector at not more than 25% LEL
- Single closed-circuit television (CCTV)-based flame detector
- Single smoke detector
- Single ultrasonic detector

Table 11.5 Example of Responses

Signal	Action				
	Alarm	**Shutdown Equipment**	**Activate Fire Suppression**	**Stop HVAC**	**Isolate Electrical Equipment**
Gas	X			X	
Confirmed gas	X	X		X	
Toxic gas	X			X	
Confirmed toxic gas	X	X		X	
Fire	X			X	
Confirmed fire	X	X	X	X	X

For a confirmed fire signal, the following are indicators:

- A single pressurized/fusible loop/linear heat detector indication
- Any combination of two detectors (except ultrasonic)

Generally, a more in-depth level of response is needed, including the use of voting systems. Table 11.5 is an example. It illustrates a sequence of responses to alarms from the fire and gas system.

Therefore, using Table 11.5, if there is a toxic gas release, an alarm will sound and the air-conditioning systems will stop. However, the plant equipment will keep running. If the toxic gas release is then confirmed, equipment shutdown will be initiated.

FIRE DETECTION

Fire detectors should be located to detect the minimum critical fire size. These are typically one of the following:

- Shortest jet flame length that could lead to process escalation
- Shortest jet flame length that could lead to structural escalation
- In the case of offshore facilities, the smallest fire that could restrict access to the temporary refuge (TR).
- Optical fire detectors should be placed such that their view of the area they are covering is not obstructed.

Fires can be detected in many ways, of which the following are the most widely used:

- Flammable gas (before ignition occurs)
- Fire/flame
- Heat

- Fusible links
- Smoke
- Manual observation

Flammable gas detection

Flammable gas detectors indicate a leak of hydrocarbons or other flammable material before ignition occurs. They generally use an internal catalyst and wire that becomes heated if flammable gases are present. The change in electrical resistance of the wire is the indication of a release. Sufficient oxygen must be present in the sample gas for this type of detector to give reliable measurements. (Catalytic-type hydrocarbon detectors with air-mixing bypasses or air dilution tubes can be used but may indicate a lower concentration of flammable gas than is actually present.) The response time for hydrocarbon detectors may be delayed when used in very cold atmospheres. (The reverse may occur with oxygen detectors.) Therefore, when temperatures are low, readings should be allowed to stabilize for a period of say 30 seconds.

Instruments of this type typically have two levels of alarm: 20% LFL and 60% LFL. If multiple detectors are installed in a single location, then a voting system can be installed. For example, if just one 20% alarm sounds, then all hot work must stop but other work can continue as normal. If three 20% alarms or one 60% alarm sounds, then an emergency response is called for.

- Special types of detector will warn of the presence of hydrogen, carbon monoxide, or hydrogen sulfide.
- Detection of releases of flammable gas should be by point or open path detectors or a combination of these.
- Flammable gas detection should be provided around high leak potential equipment, by point or open path detection or a combination of these.

Fire/flame detection

Point gas detectors should be IR type. [Catalytic detectors are susceptible to poisoning of the catalyst, can give false readings above 100% LEL, and have a slower response time than equivalent IR point detectors. Also, catalytic detectors have a mean time between failures (MTBFs) of 1–4 years and failures are most often unrevealed, leading to a high maintenance/testing load.]

For incandescent fires, optical fire detectors should be used. These may be UV detectors, IR detectors, or closed-circuit TV (or a combination of these). The choice will depend partly on the type of flame that is anticipated. For example, methanol burns with a nearly invisible flame, so a fire of this material cannot be detected by CCTV.

Open path detection should be considered for pumps and compressors if the layout of the machinery is appropriate. If this cannot be done for pumps, a detector may be located at each seal. One detector may be used between two seals provided the detector is within 1.5 meters of each seal. The detector should be located at or below the centerline of the pump and at least 0.45 meters above the ground. Some changes to location may be necessary for accessibility.

For compressors, a detector may be located as close as possible to each seal at or below the centerline for heavier than air gases and above centerline for lighter than air gases.

Heat detection

Heat detectors are usually used inside buildings. They are located according to the manufacturer's directions and the pertinent fire protection standards. Response times depend on the amount of heat transferred from the fire to the detector; therefore, the positioning of detectors should take the following into account:

- Ceiling height and depth to which the detector projects below the ceiling
- Ventilation patterns in the building
- Blockage of the heat flow to the detector due to objects

Heat detectors can also be used outside, particularly when a fire could be smoky or oxygen-limited. In these situations, rate-compensated heat detectors should be considered.

Fusible links

Where automatic deluge systems are installed, a fusible/pneumatic loop detector can be installed. The tubing melts in a fire which releases air pressure, generates an alarm, and opens the relevant deluge valve(s). Fusible/pneumatic loops may also be used in areas where confirmed fire signals are required, using a pressure transmitter connected to the loop.

Fusible links are very reliable but they do require that the fire be well under way before they work, whereas other detectors, such as fire eyes, act more quickly.

Smoke detection

Smoke detectors should be located to minimize the potential for spurious activation by ingestion of smoke from fixed diesel engines and supply vessel exhaust stacks.

Ultrasonic detectors

Leaks often make a high-pitched sound (greater than 25 kHz). Supplementary ultrasonic detection is often used as a backup to other methods. Ultrasonic detectors should possess the following features (depending on the manufacturer's recommendations).

- They should be within 8 meters of high leak potential equipment, or as directed by the detector manufacturer.

- An adjustable delay to prevent activation by short-term ultrasonic noise such as an intentional air hose disconnection. During this period, the signal from the detector is inhibited. 15 seconds is typical of the delay used in the process industry.
- Ultrasonic detectors should be calibrated according to an ultrasonic noise survey of the area in which they are installed, in accordance with vendor recommendations.
- Supplemental ultrasonic detectors should be considered around high leak potential equipment located within the unit.
- They should be located within 8 meters of high leak potential equipment.

> An important feature of ultrasonic detectors is that they are not affected by the wind.

Closed-circuit television

CCTV is often provided so that operators in the control room can check vehicle movements and maintenance activities. They can also watch equipment items such as flares to see if any operational problems are developing or to determine if they are violating an environmental standard. The same system can help with fire response—not so much with the initial detection but in providing information that can help with control of the facility and direction of the emergency response team.

CCTV-based systems cannot be used to detect methanol or other fires that burn with an invisible flame.

TOXIC GAS DETECTION

Many of the process and utility streams used in process facilities contain toxic gases of sufficiently high concentration that they could create a hazard if released. Therefore, gas detectors are required to alert workers that a release has occurred. Small releases of toxic gas may cause injury to personnel working directly where the leak occurs. Medium releases may affect other personnel working on the unit but not directly at the release source. Large releases may produce toxic concentrations outside the unit or outside the plant fence line.

Detailed information to do with toxic gas terminology and the effects of these gases on the human body are provided in *Process Risk and Reliability Management.*

Much of the guidance to do with flammable detectors can be applied to toxic gas detection also. However, the following additional issues should be considered:

- There can be two levels of alarm—similar to that discussed for flammable releases. The first level is a “toxic gas release” alarm given when one detector

is at the STEL concentration. The second is a “confirmed gas release” alarm. This signal can be given for any of the following:
  - One detector at the immediately dangerous to life and health (IDLH) concentration
  - Two (or more) detectors at the STEL concentration
- Detectors should be located within 1.5 meters of the leak point.
- When multiple sources are located together, e.g., pumps, a single monitor can serve two sources, provided the sources are located within 3 meters of one another.
- Potential releases from passive equipment such as pipe flanges and pipe/vessel wall ruptures do not usually require monitoring. However, manifolds with large number of valves and flanges, representing a concentration of leak sources, may be locally monitored if the toxic gas concentrations are high.
- Fixed H_2S detectors should be provided in high potential hazard H_2S areas defined as:
  - H_2S concentrations in the vapor phase of the contained stream are above 2% by volume.
  - Flash of a released liquid at atmospheric pressure produces a vapor with more than 2% by volume H_2S.
  - Low-lying, poorly ventilated areas where H_2S could accumulate, that are not under Permit to Work access control.
- Perimeter monitoring using open path detectors should be considered in circumstances such as close proximity to a fence line or occupied buildings. Open path detectors should be considered.

MANUAL ALARM CALL POINTS

Manual Alarm Call Points (MACs) allow an operator to initiate the emergency response system, regardless of the response of the automatic instrumentation. They can be used for any type of emergency. The typical MAC is of the open contact “Break Glass” type, suitable for Division 1 locations. MACs should be covered with a guard to prevent inadvertent alarm activation. They should be clearly visible and labeled and easily operable by personnel wearing personal protective equipment (PPE) such as gloves.

MACs should be located throughout a facility and along escape routes. Each call point should be accessible from at least two different locations. In buildings, they should be located on exit routes, especially on the floor landings of staircases and at exits to open air. They should also be located within 60 meters of any point within a process unit or module. (It may be necessary to reduce this distance if there is a high level of equipment congestion.)

When a MAC is activated, it should initiate audible and visual signals in a permanently manned location. The signal should indicate the area where the manual alarm call was initiated.

OFFSHORE FACILITIES

The discussions in the previous section apply primarily to onshore facilities. The same principles apply to offshore installations. However, there are some special issues that need to be considered when designing and operating offshore platforms and rigs. (Offshore issues in general are discussed in depth in *Offshore Safety Management.*) These special issues include the following:

- There is very little space on an offshore facility. The minimum spacing requirements that are used onshore are often not achievable.
- Escape in an emergency is difficult because there is "nowhere to run to"—except overboard.
- People who are off-duty are still present at the facility, mostly in the living quarters.

Offshore production platforms and drilling rigs are generally arranged into Safe and Hazardous Areas. The two areas should be separated from one another and may have physical barriers between them. The Safe Area will include accommodations, the control room, UPS (uninterruptible power supply), emergency power generation equipment, and nonhazardous platform utilities such as water and compressed air. The Hazardous Area contains the flare, derricks, gas compression, hydrocarbon separation, the wellhead, and drilling facilities.

The following principles should be considered when developing the layout of an offshore platform or rig.

SAFE AREAS

- Equipment and piping that contains flammable or toxic materials should be kept separate from the Safe Areas. These items should not be located within or below a Safe Area.
- Safe Areas should be protected from fire and explosion hazards with firewalls and blast walls.
- Electrical generators for normal power supply should be located as far from the process equipment as practical.
- The Safe Area should be protected from falling objects, liquid hydrocarbon overflow, explosions, and flame impingement.
- Gas detection should be installed if fuel gas is brought into the accommodation for heating or cooking purposes.
- Natural ventilation should be used as much as possible to reduce the accumulation of flammable gases or vapors.

OPERATIONS

- Interfaces such as disposal chutes, downcomers, drain tie-ins, sump locations, vent lines, consumables loading stations, and crane access should be considered in the layout design.
- It should be possible to access isolation valves during an emergency so that incoming and outgoing risers can be quickly isolated.
- Gas detectors should be provided in process and utility areas where leaks of hydrocarbon or other hazardous gases could originate, all wellhead areas, and in enclosed areas as defined in alternative to installation of gas detectors.
- H_2S detectors should be located as defined by API RP 14C.
- Hydrocarbon inventories should be kept to a minimum and be separated as much as possible from ignition sources and the Safe Areas.
- If Simultaneous Operations (see Chapter 1) such as production, drilling, and crane functions can be conducted simultaneously, the layout design must minimize potential conflicts.
- Primary fighting should be provided through fixed firefighting systems such as remotely operated hydrants/monitors and deluge systems.

EMERGENCY EVACUATION AND RESCUE

- A minimum of two separate Emergency Evacuation and Rescue (EER) routes from the process, drilling, and other hazardous areas to the Safe Area should be provided.
- The EER routes should be protected from fire hazards.
- Emergency assembly areas should be large enough to allow for donning survival gear, breathing apparatus, and firefighting gear.
- A minimum of two stairways connecting each deck should be provided. These stairways should be near opposite ends of the facility.
- Designated walkways should have adequate vertical and horizontal clearance for emergency response personnel and their equipment.
- Access/egress from two directions should be provided, where practical.
- Sufficient walkway clearance, stair/landing sizes should be provided to enable a stretcher case to be transported from anywhere on the platform to a designated medical treatment or evacuation station.

TEMPORARY REFUGE

Offshore facilities have one or more designated TR areas which serve as a muster point in the event of an emergency. It is the area where personnel can remain while attempts are made to control the emergency situation, and from which a safe and orderly evacuation can be affected if necessary. The TR will be protected against fire, blast, and smoke ingress, and will be provided with means of communicating with the rescue and support services. Generally the facility's living quarters are the primary TR.

At the TR, personnel can take one or more of the following actions:

- Assemble during an emergency
- Take refuge from fire, smoke, and other hazards
- Initiate emergency actions
- Communicate with rescue services
- Effect safe and orderly platform evacuation. Therefore, the routes from the temporary safe refuge to lifeboat and/or helicopter embarkation points should be clearly marked and well protected.

The TR should provide protection for at least 1 hour against fires, explosions, and smoke ingress. Therefore, the TR must be provided with an air supply, fire and gas detection, and smoke dampers.

The TR will provide the following functions:

- It is an emergency command center (but not a control room). So, e.g., in the case of drilling rigs, it could contain a backup BOP (blowout preventer) control panel.
- Sufficient means of communication should be provided between individuals on the installation and other installations, vessels, aircraft, and onshore.
- It provides protection for personnel and equipment. This protection can include fire and explosion walls, ventilation systems, fire control systems, and the ability to detect fire and gas.
- It will have a sufficient supply of PPE such as immersion suits and floatation aids.
- It will have protected access to evacuation points.
- It will have first aid capabilities.

There should also be a secondary TR that can be reached if the primary TR is not accessible. For example, on a ship or barge, the primary TR is the living quarters located in the superstructure at the stern of the vessel. However, if there is a fire midship and someone is in the bow area, he or she will not be able to reach the stern of the vessel, so there needs to be second TR at the bow.

Although a TR is normally thought of as being a single, box-like building (such as the accommodation quarters), the TR concept can be broadened to include areas where personnel can move about in safety. For example, some Floating Producing, Storage and Offloading Units (FPSOs) have a totally enclosed corridor running the length of the barge. This corridor provides protection from harsh weather; it also provides a safe location in case someone wants to go from one end of the vessel to the other.

The following general guidance should be considered when designing the TR:

- It should be located as far from drilling and process hazards as possible (location on a separate bridge-connected platform is best).

- It should be protected from the effects of fire, smoke, and blast through the use of physical barriers and/or passive fire protection.
- The Emergency Control Center (ECC) will often be located close to the TR. The center should provide emergency response personnel with the capability of operating the control systems that are critical to the safety of the facility.
- If the TR is not pressurized, flammable gas detection should be installed; if there is a potential for toxic gas to accumulate within the building, detectors should be installed in the building.
- Smoke detection should be provided in all internal spaces in the TR/ accommodation unless the use of the space is incompatible with smoke detection, in which case rate-compensated heat detection should be installed.

WELLBAY AREA

The following special issues should be considered for the wellbay area:

- It may require separation from other process areas by fire or blast walls. The use of splash walls for this separation provides protection only against contamination from drilling fluids.
- It should be accessible for personnel escape and firefighting on both sides of the platform.
- It should be clear of permanent equipment for the full width of the platform for drilling and workover rigs.
- No equipment should be located in the wellhead area other than wellhead fittings (including wing valves), flowlines, individual gas lift, gas injection, well kill, water injection, or chemical injection lines and the parts of the platform safety systems which serve the wellhead area.
- Valves (other than wing valves), instruments, vent lines, and drain lines should be outside the wellhead area where practical.
- Sufficient clearance above the wellheads should be provided for the installation of wireline BOPs.
- Process piping required to traverse the wellbay area should be routed outside of the wellhead area.
- Manifolds for gas lift, gas injection, water injection, well kill, chemical injection, and blowdown of wellhead piping systems are permitted in the production deck wellbay area but should be outside the wellhead area. Generally the manifolds should be located in the 4.5 meter space between the outside well rows and the skid trusses. It may be necessary to increase this space to accommodate manifolds for large, high-capacity wells/flowlines, and in these cases, it may be preferable to locate the manifolds on only one side of the wellbay area.
- Control panels with instruments related to individual wells and equipment to do with safety systems for the wellbay are generally permitted in the wellbay area.

- Test separators located on the production deck in the wellbay area are permissible provided they do not restrict explosion venting in the wellhead area to the extent of exceeding design overpressures.

DRILLING RIGS

The major drilling rig options should be considered and evaluated during the early design and layout of the platform. These options should include the following:

- A self-contained drilling rig integral to the platform
- A self-contained drilling rig either packaged in modules or handled as individual components, which can be set and removed via derrick barge or platform crane(s)
- A derrick set temporarily installed onto the platform and "tender assisted" by a floating vessel or jack-up
- Drilling from a jack-up temporarily positioned over a portion of the platform

With regard to layout of equipment on a drilling rig, the following factors should be considered:

- Rig equipment should be arranged such that there are always two escape routes from any location.
- The layout of a self-contained drilling rig or tender rig derrick set should be coordinated to ensure that an effective arrangement of rig equipment and safe distribution of rig loads is achieved.
- Adequate space should be allocated and reserved for drilling service company instrumentation/data processing units for mud logging and auxiliary wireline services. Deck space may also be need to be allocated for the cement unit (and associated equipment such as mixing tanks and liquid additive tanks) and the mud engineering lab. Estimates of the space requirements and weights of these units should be considered in early layout development. The space reserved for the mud logging unit should be as close as is safe and practical to the shale shakers.
- A diverter system should be included in the layout of the drilling rig equipment. The diverter system (diverter, vent line, vent line valves, and diverter and valve control systems) should be arranged in accordance with the requirements of API RP 64.
- Consideration should be given to the layout of the major components of the drilling rig's well control equipment, to include the layout and location of the choke/kill manifold, choke control panel, mud/gas separator, gas discharge line, trip tank, BOP, and control panels so that adequate space is provided and operational safety not compromised.
- A minimum of two BOP control panels should be provided, one of which should be on the rig floor near the driller's console.
- If the possibility of inadvertent H_2S release at the surface could yield atmospheric concentrations of more than 20 ppm, the most probable locations

of inadvertent release of H_2S should be equipped with mechanical blowers to disperse vapors. Use of such blower ventilation equipment should be considered on the rig floor, in low and confined areas such as under the derrick substructure and adjacent to the wellheads and BOP stack, at the shale shakers and above open mud tanks.
- Electrical equipment, fittings, and wiring materials associated with the drilling rig should be explosion-proof if located in a Class 1, Division 1, or Zone 1 area. Electrical area classification for the drilling rig should follow the guidelines established in API RP 500.
- For self-contained drilling rigs or tender rig derrick sets, any associated, independent offshore fire protection system; alarm and emergency shutdown systems; and relief, flare, vent, and drain systems should meet the minimum requirements established for the platform. These systems should be integrated with the overall platform fire protection system; alarm and emergency shutdown systems; and relief, flare, vent, and drain systems.

PIPELINE EQUIPMENT

- Pipeline equipment includes risers, last valve off, first valve on (LVO/FVO), and other facilities such as pig and/or sphere launchers and receivers, and associated kicker line piping and valves.
- Risers and FVO/LVOs should be located as far away from the Safe Area as practical. To prevent damage to valves, actuators and instrumentation, FVOs and LVOs should be located in areas to minimize potential risks from falling objects, liquid hydrocarbon overflow, explosions, or flame impingement.
- The LVO/FVOs should generally be located in the vertical portion of the risers below the production deck and consideration may be given to locating these valves at the sea-deck level to reduce exposure to a riser leak. If located at this level, access/maintenance platforms will be required and valve instrumentation should be protected from storm waves and corrosion.
- Adequate lateral and vertical space should be provided for pig launcher and receiver facilities for access and maintenance, including pig handling equipment. Launchers and receivers should be located away from the wellbay area, higher risk process equipment, known ignition sources, highly traveled personnel routes, and materials handling areas. Launcher or receiver doors should face outboard of the platform and away from Quarters/Safe Areas to reduce the possibility of any projectiles hitting personnel or other equipment.

FIRE PROTECTION/FIRE AND GAS DETECTION

- Firewater pumps should be located in the Safe Area and should be separated by adequate distance and/or by firewalls, to avoid the potential for a single fire/explosion in the Safe Area rendering firewater pumps inoperable. Firewater engine air intakes should be located in well-ventilated locations to reduce the possibility of smoke or hydrocarbon vapor ingestion.

- Process areas handling streams with H_2S concentrations above 100 ppm should include electronic H_2S leak detection and alarm systems.

HELIDECKS

- Helidecks should be oriented to the extent practical to take advantage of the predominant prevailing wind.
- The location of the helideck should provide unobstructed access for approach and departure takeoff areas.
- An unobstructed drop zone from the outer edges of the helideck on at least 180° of the approach/departure sector to the sea level should be provided.

TRANSFER AREAS

- Cranes and cargo laydown areas should be placed to optimize favorable vessel motions during cargo transfer. Ideally, cargo vessels will be aligned such that the seas are on the bow or forward quarter and such that the vessel will not impact the platform upon loss of engine power.
- Platform cranes should generally be capable of accessing operating and storage areas of the installation to service supply boats, construction, drilling, on ongoing production operations. Laydown areas should be provided for materials in transit.
- Pressurized production equipment and associated piping should be protected from dropped objects as practical (including dropped crane loads) and swinging loads and crane booms.
- Boat landings should be oriented on the sheltered side of the platform based on prevailing weather conditions. A ladder or knotted rope should be provided on the boat landing so that a person who falls overboard can get back on to the platform.

PIPING

- The layout of piping should consider access requirements, pipe stress, thermal expansion, and process restrictions.
- Piping should conform to the relevant codes such as ASME B31.3 and applicable piping specifications.
- Piping should generally be grouped to facilitate piping support.
- Provisions should be made for clearances between piping and vessels, piping in pipe racks, pipe flanges, and other equipment, expansion loops, headroom above access routes or access platforms, accessibility for suitable support points, valve orientation, operation and accessibility, and clearance to permit removal of in-line equipment with minimal dismantling of equipment.
- Extra space may be needed insulation.

- Piping should not be located near explosion vent areas, since an explosion will produce high gas velocities, and hence high drag forces, on the piping at such locations.
- Routing of process piping through nonhazardous areas should be avoided. If this is not avoidable, the piping should be appropriately labeled and protected from dropped objects and should be of welded construction and not smaller than NPS 1½ inches nominal diameter.

ROTATING EQUIPMENT

- Compressors and pumps should be located in well-ventilated areas and as far from the Safe Area as practical.
- Gas turbine air intakes should be located so as to minimize salt ingestion and to avoid intake of exhaust air from air fin heat exchangers.
- Gas turbine exhaust stacks should be located to avoid recirculation of hot exhaust gases to the turbine inlet air system. A minimum of 6 meters of vertical separation between air intake and exhaust outlet is often recommended.
- Gas turbines should be enclosed, cooled, and ventilated by forced, filtered air. If the air does not come from a safe location, gas detectors should be located in the inlet and exhaust air passages.
- Gas detectors should be located in the exhaust air passages.
- The impact of gas turbine exhaust heat plumes on helicopter and crane operations should be evaluated.
- Layout of rotating equipment should provide room for maintenance, removal, and replacement of rotors and other major components.

CHAPTER

12 Equipment

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00012-3

INTRODUCTION

This chapter discusses some of the design and operating issues to do with specific equipment items. Covered are:

- Pressure vessels
- Storage tanks
- Pumps
- Compressors
- Heat exchangers
- Fired heaters
- Internal combustion engines
- Electrical equipment.

PRESSURE VESSELS

Pressure vessels operate with internal pressures that are either above or below atmospheric pressure. They rely on the strength of their walls and flanges to prevent failure. Because of the potential danger associated with the rupture of pressure vessels there are many codes and standards to do with their design, fabrication, and inspection.

REGULATIONS AND STANDARDS

API 510 (2006)—Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration—provides guidance for the inspection of pressure vessels. The contents for the 2006 edition of this document are given in Table 12.1.

The standard lists the following 15 elements as part of an asset integrity quality control and inspection program:

1. Organization and reporting structure for inspection personnel
2. Documenting and maintaining inspection and quality assurance procedures
3. Documenting and reporting inspection and test results
4. Corrective action for inspection and test results
5. Internal auditing for compliance with the Quality Assurance Inspection Manual
6. Review and approval of drawings, design calculations, and specifications for repairs, alterations, and reratings
7. Ensuring that all jurisdictional requirements for pressure vessel inspection, repairs, alterations, and reratings are continuously met
8. Reporting to the authorized inspector any process changes that could affect pressure vessel integrity

Table 12.1 API RP 510 Contents

1. SCOPE
    - 1.1 General Application
    - 1.2 Specific Applications
    - 1.3 Recognized Technical Concepts
2. REFERENCES
3. DEFINITIONS
4. OWNER/USER INSPECTION ORGANIZATION
    - 4.1 General
    - 4.2 Owner/user Organization Responsibilities
5. INSPECTION, EXAMINATION, AND PRESSURE TESTING PRACTICES
    - 5.1 Inspection Plans
    - 5.2 Risk-based Inspection (Rbi)
    - 5.3 Preparation for Inspection
    - 5.4 Inspection for Types of Damage Modes of Deterioration and Failure
    - 5.5 General Types if Inspection and Surveillance
    - 5.6 Condition Monitoring Locations
    - 5.7 Condition Monitoring Methods
    - 5.8 Pressure Testing
    - 5.9 Material Verification and Traceability
    - 5.10 Inspection of In-service Welds and Joints
    - 5.11 Inspection of Flanged Joints
6. INTERVAL FREQUENCY AND EXTENT OF INSPECTION
    - 6.1 General
    - 6.2 Inspection During Installation and Service Changes
    - 6.3 Risk-based Inspection
    - 6.4 External Inspection
    - 6.5 Internal and On-stream Inspection
    - 6.6 Pressure-relieving Devices
7. INSPECTION DATA EVALUATION, ANALYSIS, AND RECORDING
    - 7.1 Corrosion Rate Determination
    - 7.2 Remaining Life Calculations
    - 7.3 Maximum Allowable Working Pressure Determination
    - 7.4 Fitness for Service Analysis of Corroded Regions
    - 7.5 API RP 579 Fitness for Service Evaluations
    - 7.6 Required Thickness Determination
    - 7.7 Evaluation of Existing Equipment with Minimal Documentation
    - 7.8 Reports and Records
8. REPAIRS, ALTERATIONS, AND RERATING OF PRESSURE VESSELS
    - 8.1 Repairs and Alterations
    - 8.2 Rerating
9. ALTERNATIVE RULES FOR EXPLORATION AND PRODUCTION PRESSURE
    - 9.2 Definitions
    - 9.3 Inspection Program

Table 12.1 API RP 510 Contents *(Continued)*

9. Training requirements for inspection personnel regarding inspection tools, techniques, and technical knowledge base
10. Controls necessary so that only qualified welders and procedures are used for all repairs and alterations
11. Controls necessary so that only qualified nondestructive examination (NDT) personnel and procedures are used
12. Controls necessary so that only materials conforming to the appropriate pressure equipment codes are used for repairs and alterations
13. Controls necessary so that all inspection measurement and test equipment is properly maintained and calibrated
14. Controls necessary so that the work of contract inspection or repair organizations meet the same inspection requirements as the owner–user organization
15. Internal auditing requirements for the quality control system for pressure-relieving devices

FACTORY ACCEPTANCE TESTS

Equipment and control systems are generally tested at the factory where they were manufactured or assembled before being shipped to the project site. The basic purpose of the Factory Acceptance Test (FAT) is to ensure that the equipment meets the requirements specified in the purchase order and the related engineering specifications.

During the test, the following activities will be carried out:

- A check that all drawings and manuals are provided and that they match the equipment as built.
- A check of capacity and utility requirements.
- A check that the equipment is properly labeled.
- A check of measurements and tolerances and potential leaks.

- A check that the human−machine interfaces are workable.
- An evaluation of the number and type of spare parts needed in the first year of operation.
- Tests of system software and communication with other equipment items (some of this will have to be done after the item is shipped to the project site).
- A check for potential installation problems.
- A check that manuals and operating procedures are provided.
- A determination as to what training the operators and maintenance technicians will require.

Once an equipment item has passed the FAT, it will be transferred to Operations, often through use of a Mechanical Completion Certificate.

VESSELS UNDER VACUUM

Vacuum vessels or towers have a normal operating pressure that is below atmospheric pressure. They are standard pressure vessels, but the following issues should be noted:

1. Generally, vacuum towers are significantly larger in diameter than other towers because the density of the gases and vapors in them is so low.
2. Leaks will be from the atmosphere into the vessel. This means that, if the tower contains hydrocarbon vapors, a leak could create an explosive mixture inside the vessel. In refinery vacuum towers, this potential problem is a particular concern in the overhead system between the primary overhead condenser and the vacuum jets.
3. Refinery vacuum towers operate at temperatures where coking of internals or upsetting of trays can occur very quickly.

REFLUX VESSELS

Reflux vessels feed cool liquid to columns and vessels. Therefore, during an emergency, the reflux system will generally be kept in operation to ensure that heat continues to be removed. The reflux vessel and its associated pumps and piping should be protected against external fire, either with fireproofing or water sprays.

SMALL PIPE CONNECTIONS

The number of small pipe connections on a vessel should be limited. Threaded gauge connections, sample points, and level control nozzles are all subject to mechanical damage, vibration fatigue, and corrosion. The potential failure points are minimized by:

- Installing only those connections actually needed.
- Making the pipe attachments as short as possible.

- Using extra heavy pipe nipples and ¾ feet minimum diameter to the first valve off the vessel.
- Using socket-weld fittings, especially between the vessel and the first valve.

STORAGE TANKS

Unlike pressure vessels, storage tanks are not designed to handle either high pressure or vacuum conditions. Typically, the tank is open either to the atmosphere or to a part of the system (such as a flare or vent header) that is guaranteed to be at atmospheric pressure.

Representative test, inspection, and repair methods for storage tanks are given in Table 12.2.

Broadly speaking, storage tanks fall into one of two categories: fixed roof and floating roof. They are illustrated in Figures 12.1—12.3.

FIXED ROOF TANKS

A fixed roof tank contains liquid with a vapor space above it, as illustrated in Figure 12.1. When the tank is being filled, vapors are discharged through the vent. If the vapors are hazardous or detrimental to the environment, they will be discharged to a scrubber system and/or a flare. The vent must be big enough to handle the maximum flow of liquid into the tank, as demonstrated by two Process Safety Beacon reports CCPS (2002) and CCPS (2003) in which the vents were not big enough and tank rupture occurred.

When the tank is being emptied gas must be added to the vapor space, otherwise the tank could collapse. If the liquid material is flammable it is normal practice to add nitrogen or some other blanketing gas, such as fuel gas, that does not contain oxygen.

Steel tanks over 5 meters in diameter do not generally need ground rods for lightning protection. These tanks are considered adequately grounded because of the contact between the tank bottom and earth. When adding nonconductive tank bottoms or liners to the tank for leak protection, ground rods are needed.

Table 12.2 Test, Inspection, and Repair Methods for Storage Tanks

Program Element	Program Requirements
Design Basis/Requirements	API: 12D, 12F, 650 or 620.
Inspection/Test Procedures	Inspection API-570.
Inspection/Test Frequencies	API-653—adjusted according to operating experience.
Inspection/Test Acceptance Criteria	API: 12D, 12F, 650 or 620 to determine if repairs are needed.
Repair and Alteration Procedures	API-653

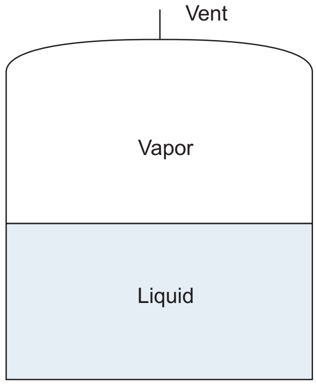

FIGURE 12.1

Fixed roof tank.

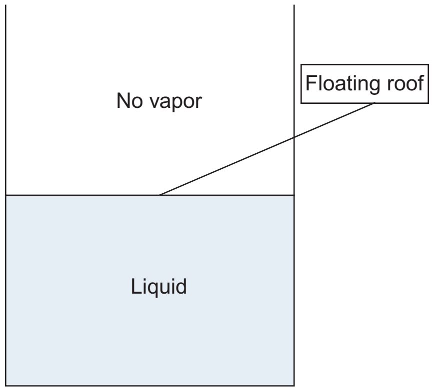

FIGURE 12.2

Floating roof tank.

The flow of nitrogen into the tank can be continuous or it can be controlled by pressure or the concentration of oxygen in the vapor space. It is generally the most efficient in terms of nitrogen use. Nitrogen use can be calculated using tables in API 2000 (2009) and ISO 28300 (2008).

Vapor recovery systems on tanks and vessels can result in vapors in the flammable range being released. In order to minimize the potential for a fire, the following guidelines should be considered:

- Vapor lines should be electrically conductive to prevent static buildup.
- Use of mechanical equipment to move vapors should be minimized. If it has to be used then it should be nonsparking.
- Atmospheric vents should be located well away from possible ignition sources.

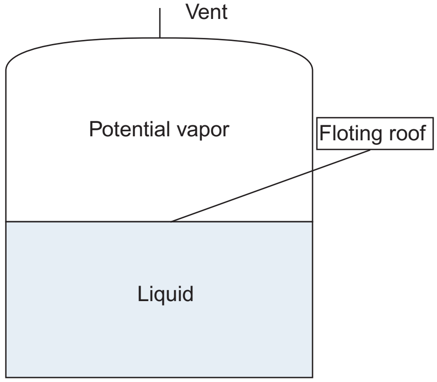

FIGURE 12.3

Covered floating roof tank.

- Unclassified electrical equipment should be at least 20 meters away from vapor recovery equipment.
- In waste handling facilities, activated carbon adsorption units can be overheated to ignition temperatures. These systems should be protected by detonation arresters and high bed temperature shutdowns.
- Flares, thermal oxidizers, and incinerators are open flame devices that may require flame arrestors or other devices to prevent flashback.

FLOATING ROOF TANKS

The basic idea of a floating roof tank is that the roof is in contact with the liquid surface. It is attached to the sides of the tank with rollers. A seal between the moving roof and the tank wall prevents process vapors from leaking into the space above the roof. As liquid is added, the roof moves up; as liquid is removed, the roof moves down. At no time is there a vapor space directly above the liquid. Hence there is no need to vent the tank when it is being filled and there is no need to add inert gas when it is being emptied.

Many floating roof tanks do not have a fixed roof. Hence, when looking down on a large tank farm from an airplane, it is possible to see the status of the roof positions by looking down on them. This type of tank is illustrated in Figure 12.2. Some floating roof tanks have a fixed roof above the floating roof as shown in Figure 12.3.

Many tank fires are caused by lightning (either induced charges or direct strikes). The following actions minimize the chance of a fire:

- The roof seals should be maintained in a good condition.
- Floating roofs should be bonded to the tank walls by the use of shunts spaced at least 3 meters apart. The shunts should be in contact with the wall of the tank.
- The tank roof should be kept clean.

- All openings such as manways and inspection hatches should have sealed covers.
- Pontoons need to be inspected at least annually for presence of liquid or flammable vapors.

The potential for contamination of the atmosphere above the internal floating roof is great. Entry onto the roof of an internal floating roof tank constitutes entry into a confined space, so confined space entry procedures must be followed. Provisions for personnel support and distribution of weight must be provided when personnel are on the internal floating roof.

The internal floating roof in a covered tank may be a steel pontoon roof, a steel pan roof, an aluminum floating cover with pontoons or floats, or a fiberglass polyester skin panel deck. Aluminum and polyester roofs have a greater fall through potential than steel roofs. In addition, mechanical damage, corrosion, or other defects may not be readily apparent.

The following guidance applies to work carried out on the roof of a floating roof tank:

- The level of the floating roof should be within about 8 feet of the top of the tank, and no product movement should occur into or out of the tank for 24 hours prior to entry.
- The roof should be essentially horizontal with no evidence of tipping or "hanging up."
- The vent shown in Figure 12.3 should also be a vacuum breaker for use when the tank roof is falling.
- Workers should not enter the floating roof space to determine if liquids are present.
- No entry should be allowed if significant liquid hydrocarbon is present or is suspected to be present on the floating roof.
- Suitable personnel protective equipment should be used.
- Adequate roof support should be assured before anyone walks on the roof.
- Electrical equipment, including lighting, that is used during inspection/work on the internal floating roof should be explosion proof.
- On large-diameter tanks, more than one entry point should be provided to lessen the distance to be covered from the entry point and to minimize the possibility of air and tag (rescue) lines becoming entangled around columns.
- Hot work should not be permitted inside the space of an in-service internal floating roof tank.

PUMPS

Pumps are at the heart of all process facilities. They are also a source of hazards because they have moving parts and a seal between their contents and the atmosphere. Hence they are more likely to leak than vessels or piping. If the pump contents are above the liquid's flash point, then a flammable vapor cloud could form.

PUMP CASING

Pumps will generally have steel or alloy casing. The use of cast iron casing should be limited to nonhazardous, noncritical service, and such pumps must be installed in such a manner that connecting piping will not excessively stress pump cases.

Although pump casing failures are likely to be extremely serious, they are also quite rare. Causes of casing failure include overpressure, mechanical stress, and reaction with the process materials. If the internal rotating or reciprocating element fails, then there is likely to be a major process upset. However, such a failure will probably not create safety problems because the casing will remain intact. Casing failures are normally very serious because:

- They can lead to a major release of process chemicals.
- The casing sometimes serves as a support for the other equipment.
- As it fails, the casing may send fragments of metal flying through the air—these can injure people and seriously damage other equipment.

Small fittings on pump cases for pressure gages, sample connections, vapor vents, and drains should be seal-welded to the pump case up to the first valve. Where vibrations may be severe, the fitting should be braced.

SEALS AND PACKING

Seal failures are the most common type of failure associated with rotating equipment. Since seals are a barrier between the process and the atmosphere, such failures are often likely to lead to environmental problems, and potentially a safety problem depending on factors such as the flammability/toxicity of the process fluid, the size of the leak, and its proximity to personnel or ignition sources. Seal failures can be caused by problems with the bearings, couplings, and shaft vibration.

Mechanical seals, either single or double, are generally preferred over packing because of their higher reliability, longer life, and lower probability of leakage. Double seals reduce the frequency of seal failures and also reduce the consequences of a leak that may occur.

Where serious hazard might result from leakage, pumps handling hot oils in excess of 175°C should be fitted with water quench glands. Water deluge should be provided over pumps handling liquids above their autoignition temperature or above 315°C. Water sprays should be remotely operated from a point at least 15 meters from the pump being protected.

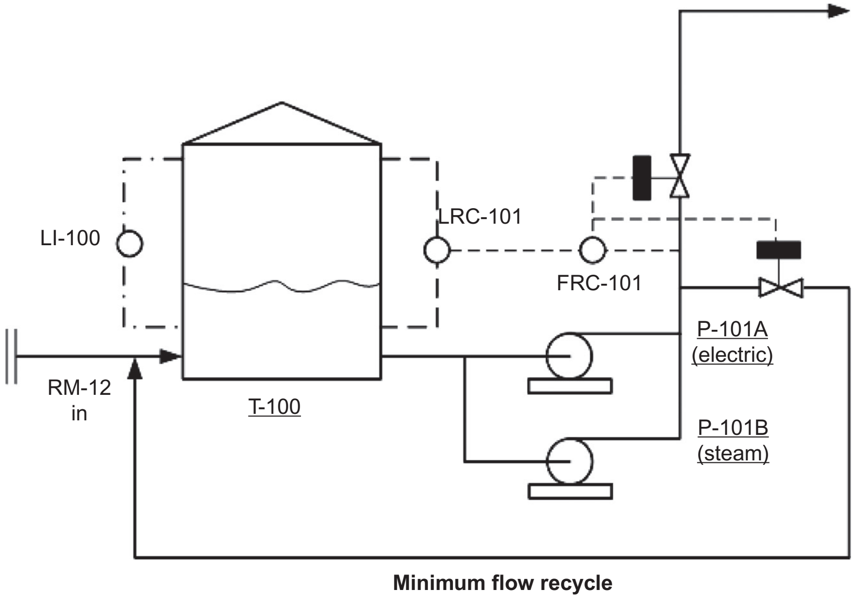

FIGURE 12.4

Minimum flow bypass.

MINIMUM FLOW BYPASS

A common cause of seal failures of centrifugal pumps is blocking in the pump while it is still running (or starting up the pump with the discharge block valve closed). Although this scenario is not usually hazardous for a short period of time, it can lead to overheating and seal failure. Cooling water pumps, e.g., have been known to rupture when blocked in while running. The water in the casing is heated to the point where it starts to boil, the seal leaks, but not enough to relieve the rapidly rising pressure, and so the casing ruptures.

When a blocked discharge could be a problem, or when large turndown ratios are anticipated, the installation of a minimum flow bypass should be considered. This type of bypass opens when the flow of liquid leaving the pump falls below a minimum value. The bypass returns discharge liquid to the suction of the pump. Since the liquid is heated as it goes through the pump, it may be necessary to put a cooler on the recycle stream, or to have the recycle stream flow to a suction tank or vessel that contains a large inventory of liquid.

Figure 12.4 is based on the first standard example. If the flow of liquid through FRC-101 falls below a minimum value, the bypass valve opens and RM-12 is recycled into T-100. The inventory in T-100 is sufficient to cool the recycle stream.

PUMP ISOLATION

To prevent escalation of an incident, emergency isolation valves for the suction of pumps should be considered when the pump is fed by a vessel containing 10 cubic meter or more of inventory of materials that are flammable or toxic. In critical services, the valves on either side of the pump should be able to close quickly—usually through an automatic shutdown systems. They should also be fireproofed. If manual isolation valves are used, they should be at least 15 meters from the pumps or the likely location of a fire.

Emergency isolation valve design options include the following:

- Retrofitting an existing pump suction valve with an actuator
- Installing a quarter turn fire-safe valve with a fail-safe mechanical spring actuator
- Installing a quarter turn fire-safe ball valve or butterfly valve with an air piston or diaphragm actuator
- Installing a spring loaded quick closing valve
- Installing an air or electric motor-operated valve with fireproofed actuator and controls.

For pairs of pumps, an emergency isolation valve should be installed on the suction of each pump so that the valves can be tested during normal operations.

Thermal pressure relief valves may be needed for low or ambient temperature pumps that can be blocked in and that could be exposed to sunlight or another heat source.

SAFETY ISSUES

Pumps should be checked for the following potential problems:

- Cracks or holes in the casing
- Failure of small piping attachments
- Thread corrosion on plugs and pipe nipples
- Inadequate thread engagement
- Seal or packing leaks
- Poor gasketing

For high-pressure, high-temperature, and high-capacity pumps, the following protective instrumentation should be considered:

- Low suction pressure alarm
- Vibration monitoring and shutdown
- High bearing temperature alarm
- High discharge pressure alarm
- Seal failure (leak) alarm (for double seal pumps)

COMPRESSORS

Many of the comments made about pumps can also be made about compressors. They also have moving parts and seals which are liable to failure.

LIQUID KNOCKOUT ON THE COMPRESSOR SUCTION

One of the most serious failure modes for a compressor is for liquid to enter the casing. The result of this failure could be a catastrophic failure of the casing and/or the compressor internals. Liquid knockout pots and scrubbers are ordinarily provided in suction lines for this purpose. High-level alarms and compressor shutdown devices should be installed on knockout pots and scrubbers.

RELIEF VALVES

Adequate relief valve capacity must be provided for each cylinder or group of cylinders on a positive displacement compressor discharging into a common header. The discharge from these valves must extend outside any compressor enclosure.

COMPRESSOR ISOLATION

The general principles to do with isolation valves are similar to those for pumps, as discussed above. In addition, ventilation of the packing area must be designed so that flammable gases do not flow into the crankcase as this would pose a serious explosion risk.

Air leaks into a compressor, or residual air left after a shutdown, may create an explosive hazard. For this reason, it is advisable to provide purging lines to the compressor; they will be used after the compressor has been opened to atmosphere. It is also a good practice to eliminate unnecessary vents on suction lines and to minimize bypass lines and valves connecting discharge and suction lines.

Ventilation of the packing area must be designed so that flammable gases are not forced into the crankcase. This would pose a serious explosion risk due to the presence of air. Vents should be extended outside and above the eaves of any enclosure.

Where pulsating discharge from reciprocating compressors results in pipe vibration so serious that piping and equipment may fail, the installation of additional pulsation dampeners may be warranted.

SHUTDOWN AND ALARM SYSTEMS

Compressors should be provided with shutdown stations at expected personnel access points and at a safe distance from the equipment so that, in the event of a hazardous occurrence, the compressors and their drivers can be controlled and shut down without endangering personnel.

Typical alarm and shutdown considerations for major compressor/turbine installations include the following:

- A high-level alarm on a knockout drum immediately ahead of a compressor, a high−high level switch to shut down the prime mover, and an alarm to indicate that the machine has shut down.
- A low-pressure local alarm on the lube oil to a turbine or a compressor, a low-low pressure switch to shut down the prime mover, and an alarm to indicate that the machine has shut down.
- A low differential pressure or low oil pot level on the seal oil system, a low−low seal oil differential pressure or low−low seal oil pot level switch to shut down the prime mover, and an alarm to indicate that the machine has shut down.
- Additional shutdown systems include the following:
  - High vibration
  - Low suction pressure or low flow
  - High discharge pressure (for reciprocating compressors)
  - High discharge temperature
  - High bearing temperature
  - Axial displacement
  - Overspeed
  - Low fuel pressure or flame failure (for gas turbines)
- High case temperature (for large electric motor drivers)
- Overload (for large electric motor drivers)

HEAT EXCHANGERS

Safety and operability issues to do with the following different types of heat exchanger are discussed in this section.

- Shell and tube (a sketch of a shell and tube heat exchanger is shown in the example in Chapter 1)
- Air-cooled
- Cooling towers
- Air preheaters
- Boilers

SHELL AND TUBE HEAT EXCHANGERS

Shell and tube heat exchangers seldom have pressure relief valves for fire exposure because vapors will quickly flow to the next pressure vessel, from which they can be discharged. The "two-thirds rule" from API RP 521 states:

> *For relatively low-pressure equipment, complete tube failure is not a viable contingency when the design pressure of the low-pressure side is equal to or greater than two-thirds the design pressure of the high-pressure side. Minor leakage can seldom result in overpressure of the low-pressure side during operation.*

If the above rule is satisfied, then a relief valve on the low-pressure side of the exchanger is not needed provided the following contingencies are true:

- An engineering study is performed to verify that the low-pressure side of the exchanger is able to absorb the flow rate through the rupture without overpressuring the exchanger.
- There are no block valves, check valves, or automatic control valves on the low-pressure inlet or outlet piping systems that may isolate the exchanger.
- Operating procedures require that the high-pressure side be isolated before the low-pressure side and that the exchanger be immediately drained upon being removed from service. Also, the exchanger must remain drained while it is out of service.
- The valve isolating the vessel and the exchanger will generally be a horizontal stem and manually operated gate that is locked open.
- The hot-side fluid is not hot enough to boil the cold-side fluid at the design pressure.

Shell and tube exchangers do sometimes have thermal relief valves to protect against overpressuring the cold side.

AIR-COOLED EXCHANGERS

An air-cooled exchanger generally has a fan that forces air across the tubes that contain the process fluid that is to be cooled. Air coolers in hydrocarbon service are susceptible to severe fire damage because the draft created by the fan pulls up heat from fires that occur at a lower elevation. This risk can be reduced by locating equipment with high-potential fire risk such as pumps and compressors away from overhead air coolers.

Fan failure can cause extreme vibration resulting in line flange leaks. Also, failed fan blades can damage piping and endanger personnel. Vibration switches that can be set to shut the fan down before vibration reaches a destructive level are recommended for all air coolers. Also, limiting the maximum tip speed to 50 m/s will decrease the vibration and noise levels of the air cooler.

COOLING TOWERS

Figure 12.5 shows the arrangement for a typical forced-draft cooling tower.

Cooling tower failure or loss of cooling water flow can lead to emergency shutdowns and the potential for hydrocarbon leaks and fires. Consequently, spare cooling water pumps should be provided and their drivers (either electric or steam) should be very reliable.

If a heat exchanger that uses cooling water experiences an internal leak, either in one of the tubes or at the tubesheet, and if the process pressure is greater than the cooling water pressure, then flammable materials will enter the cooling water. They will then go to the cooling tower where they will evaporate

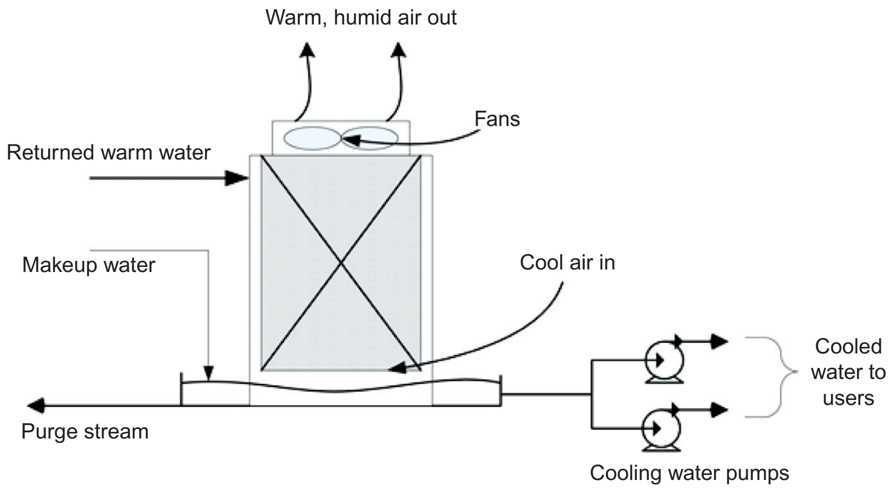

FIGURE 12.5

Cooling tower.

and possibly catch fire. Therefore, where possible, heat exchangers that use cooling water should have a higher pressure on the water side than on the process side. Then, if there is a leak, water will enter the process stream. In general, this is a less hazardous situation than that where hydrocarbons enter the cooling water.

To minimize potential problems with hydrocarbon in cooling water, the following precautions should be taken when designing cooling towers:

- Cooling towers should be electrically classified. Fan motors, pump motors, and other electrical apparatus should meet Class I, Division 2 requirements.
- Cooling towers should be located away from process equipment and furnaces.
- Disengaging standpipes or chambers should be installed on the water return line to the cooling tower to release gases before the water reaches the tower water distribution system.
- The cooling water pumps and their switchgear should be located at least 3 meters from the base of the cooling tower.
- The fill material in the tower should be noncombustible.
- Two manual shutoff switches for fans should be installed at the cooling tower, one at grade and one at the top deck. Vibration cutout switches should also be installed.
- A hydrocarbon detector should be placed in the cooling tower plume. This will notify the operators that there is a leak in the system (although it can be difficult to know which particular equipment item is leaking.

- Hydrants with monitors should be spaced such that any area of the cooling tower can be covered by streams from at least two directions.

FIRED HEATERS

Fired heaters transfer heat directly from a flame to a process fluid that usually flows through a set of tubes. They are used when the process material has to be heated to a high temperature. Some operational and safety considerations to do with fired heaters are discussed in this section.

API 560 (2007) provides guidance to do with the design and operation of fired heaters.

START-UP OF FIRED HEATERS

The lighting of fired heaters has the potential to create an explosion. Two issues are of particular concern. The first is that the firebox is filled with a flammable mixture of hydrocarbon gas and air (oxygen). If a burner is ignited, an explosion will occur. The second concern is that a furnace is operating normally, and then the fuel gas supply fails thus causing the burner flames to go out. If the fuel gas supply is then restored, an unburned mixture of gas and air can enter the hot fire box and ignite.

Conditions under which furnaces are safe to operate can be deceptive in appearance. They look dangerous when they are in operation, and they appear to be harmless when not in operation. Actually, a furnace may be most hazardous when it is inoperative or in a turndown condition where flameouts can occur resulting in unlit fuel gas filling the firebox. This situation can lead to an explosion when attempts are made to light or relight a furnace. Most furnace explosions occur when burners are being lighted and result from failure to adequately purge the firebox. Incidents are 10 times more likely to occur during a start-up especially after an abnormal shutdown. The following guidance to do with the start-up of fired heaters is provided:

- Temporary or unusual furnace operation shall be addressed in written procedures to reduce the risk of flameout in the furnace.
- After a unit shutdown
  - Furnace fuel gas and pilot gas systems shall not be put into service until immediately before the furnace is to be lighted.
  - Fuel gas lines shall not be purged into the firebox unless sufficient draft has been established.
  - Fuel gas lines are checked to be liquid free.
  - Burner and pilot gas valves are fully closed before pulling blinds.

- All air doors and stack dampers should be wide open prior to purging the furnace. Primary air registers on premix gas burners should be closed prior to lighting to prevent flashback.
- A visual inspection of the firebox must be done prior to lighting to ensure that all debris or flammable materials are not present.
- Immediately prior to lighting pilots or burners, the firebox must be purged, generally either steam or air from the furnace fans. Ensure that the entire furnace is purged of hydrocarbon and a draft is established. Adjust the main stack dampers to always provide adequate draft during the lighting process.
- If igniters are not available, an approved gas torch can be used.
- Strong winds can cause increased draft in upwind burners. Wind direction should be considered when lighting pilots and burners.
- Each flame must be stable before the next burner is lit.
- The person lighting a burner should always stand to one side so as to minimize the risk of injury from blowback.
- Operating procedures must state the maximum amount of time allowed for the burner to light. If the burner does not light in the specified period, the gas flow to that burner should be stopped and the torch removed.
- The firebox must be repurged before attempting to relight the burners.
- Process side flow is not required prior to lighting pilots because the heat generated from pilots will not damage furnace tubes. However, process side flow must be established prior to lighting any burners.
- For furnaces that are equipped with pilots, all operable pilots need to be confirmed lit before lighting any main burner.
- Once the fuel ignites, open the primary air registers until the yellow flame turns blue. Do not blow out the flame by opening the register too much or too quickly. If a torch was used to light the burner, keep it in place until the flame is steady.
- Light each pilot or burner in the same manner as the first one. *Never* light one burner from another; to do so invites explosion. Increase the fuel gas flow with the control valve or control valve bypass to maintain steady gas pressure and stable flames. Inspect the firebox frequently. A lighted burner may go out in a cold firebox.
- After all burners are lit and in operation, if one burner goes out, shut off fuel to that burner for a minimum 5 minutes and then relight with a torch or the pilot.
- If the furnace is to be dried out after repairs, light pilots and burners in a stepwise approach according to special procedures. Furnace temperatures can reach as high as 120°C with just the pilots lit.
- If burners reach their minimum fuel gas flow, a flameout may occur. During turndown situations, typically all burners in a furnace do not need to be lighted. It is better to remove some burners from service and maintain the fuel

gas control valve "in control" with the fuel gas block valve wide open than to operate all burners with the block valves pinched back. Low-NO_x burners are particularly sensitive to turndown conditions.

AIR PREHEATERS

Air preheaters raise the temperature of the air entering burner system using hot exhaust gas. They generally fall into one of the following categories:

- Rotary regenerative
- Tubular recuperative
- Plate recuperative

The moving parts associated with the rotary type of preheater make them more susceptible to a fire than the recuperative type.

The majority of the fires in air preheaters result from combustible deposits that are carried by the flue gas into the preheater and accumulate on heat-transfer surfaces. Fires are usually initiated by the deposited soot at a temperature within the normal operating range. The fire can be sustained from the oxygen in the iron oxide in the preheater.

These self-sustaining fires are difficult to extinguish. Steam cannot be used because it will react with high-temperature carbon in the water/gas reaction to produce carbon monoxide, carbon dioxide, and hydrogen, along with large quantities of heat—thus increasing the extent of the fire and the resulting damage. Water can be effective if deluge sprays are installed in all four sectors of the ducting of a regenerative type air preheater, thereby completely blanketing the entire heat-transfer surface with water.

FIRED HEATER BURNOUT

Fired heaters rely on the flow of process fluids through the tubes to keep tube and firebox temperature down. If the temperature of the process fluid leaving the heater falls, the temperature indicator on the discharge stream calls for more fuel to be fed to the burners.

The difficulty with the above arrangement arises if the flow of process fluid is stopped for any reason the outlet temperature will fall, thus causing the flow of fuel to be increased. However, without the flow of process fluid, there is no means of removing the heat that is being added (rather like putting an empty kettle on a stove). Hence the tubes will get hotter and hotter until eventually they fail (or the catalyst that is in them is irreversibly damaged).

One solution to the above problem is to put a flow measuring device on the fluid stream. If the flow of process fluid falls below a threshold value, the heater will be automatically shut down.

BOILERS

Boilers are subject to extensive code and regulatory requirements. All boilers should have the following minimum safety controls:

- A pressure relief safety valve capable of relieving overpressure at maximum heat input
- Low and high water alarm, and low–low and high–high water alarm and interlock to shut off fuel input
- Alarms and interlocks on airflow to shut off fuel supply in the event of forced-draft fan failure

Gas-fired boilers should have the additional controls listed below. These controls should cause the safety shutoff valves to close if a condition they monitor deviates from normal, which are as follows:

- Low and high gas pressure switches
- Main burner and pilot double-block-and-bleed safety shutoff valves
- Flame failure scanners with the time-limiting “trial for ignition” feature included in the circuitry

On boilers with under boiler air ducts, faulty or plugged fuel oil burners can cause fuel oil to back up into the air ducting where it will accumulate and burn. Provision for injecting fire foam or steam should be provided.

INTERNAL COMBUSTION ENGINES

Internal combustion engines have many applications in both stationary and mobile equipment, but these are the sources of ignition when exposed to a flammable mixture of hydrocarbon vapor. Types of internal combustion engine found in the process industries include the following:

- Large stationary engines—commonly used as gas-fueled drivers of large compressors or pumps.
- Intermediate size stationary engines fueled by gas, gasoline, diesel, or LPG and used to drive pumps, compressors, generators, mixers, and other equipment.
- Mobile engines fueled by gasoline, diesel, or LPG and used to drive mobile equipment including cars, trucks, cranes, forklifts, pumps, generators, and front-end loaders.

Cars, trucks, and other motorized vehicles normally used for highway transportation should not be permitted to enter process units, tank farms, and restricted locations until the area has been checked with a combustible gas indicator to ensure that concentrations of flammable vapors do not exceed 25% of the lower flammable limit (LFL).

A modified internal combustion engine is less likely to be an ignition source than an ordinary engine. When special operating conditions justify modifying and maintaining this equipment, the recommendations of this section should be considered. Where it is not practical or economical to modify a permanently installed internal combustion engine, an acceptable alternate is to provide adequate ventilation to prevent accumulation of hydrocarbon vapor in concentrations above 25% of the LFL. The engine may be enclosed in a pressurized area to exclude vapor or ventilated with an air sweep that will ensure vapor concentration will never reach the flammable range. Automatic shutdown should be provided in the event of a ventilation system failure.

Generally, the fire loss risk should be evaluated on the basis of:

- The probability of a hydrocarbon vapor release near the engine.
- Characteristics of the engine (fuel and ignition systems).
- Existing fire protection facilities (equipment spacing, fire walls, detection, and extinguishing systems).

The same detection and control systems recommended for larger stationary gas-fueled engines driving compressors and other equipment should be considered for other critical or high-risk equipment. Fire and combustible gas detectors should be employed to sound alarms or shut down operating equipment, shut off fuel supply, activate motor-operated valves to close all intake and discharge lines, relieve pressure to a vent stack, or activate fixed extinguishing systems. These detection systems are recommended for all critical unattended or not-regularly-attended facilities.

For enclosed internal combustion engine facilities, the detection system should alarm and activate any emergency ventilation systems to keep air in the facility below 20% of the LFL. If the combustible levels continued to rise up to 60% of LFL, the detection system should activate further protections (e.g., shutting down the ventilation and shutting down the engine). Another consideration should be the location of ventilation exhausts with respect to outside ignition sources.

Fixed fire control systems such as firewater monitors or water sprays over critical or high-risk equipment or carbon dioxide flooding of enclosures should also be considered. Except for combustion gas turbine enclosures, situations warranting such protection are not common.

STARTER SYSTEMS

The starter system can be electrical (Class I, Division 2), pneumatic, hydraulic, spring recoil, or inertia. It may be acceptable to use an electric starter motor that does not meet the area classification requirements if proper entry permits are used and one of the following criteria is satisfied:

- A lockable switch is provided so that the electric starter motor can be locked out to prevent its use in a classified area.
- The starting battery is kept outside the classified area and the engine is started there.
- The starter, the starter motor switch, and the solenoid are inspected to be sure they are not an open device.
- The starter motor should have a tight fitting cover band with a gasket installed to shield commutator arcing.
- The starter motor switch should have a tight fitting cover or the switch cover.
- Terminals should be covered with protective boots to avoid accidental shorting.

Large internal combustion engines are often started with air. This air is provided by a compressor—typically a conventionally lubricated reciprocating machine—and then piped to an air distributor on the engine. Explosions can be caused if combustible lubricant is present in the air. Therefore, noncombustible lubricants should be used.

INTAKE, EXHAUST, AND FUEL SYSTEMS

The following guidelines apply to intake, exhaust, and fuel systems:

- Combustion air for all internal combustion engines should come through filtered air intakes. Engine exhausts should extend above the eaves of the building. The exhaust system for stationary engines with higher risk exposures should be leak-tight so flames from a backfire cannot escape, and they should be equipped with a spark-arresting type of muffler.
- Fuel lines should be of steel tubing or piping with flexible steel or steel-braided tubing sections where necessary to absorb pipe vibration. They should be located with at least 50 millimeters clearance from exhaust and electrical systems.
- Fuel lines, valves, fittings and vents should be located so that leakage will not drip on electrical or exhaust systems. Steel shutoff valves located for access in time of fire should be provided in main fuel lines.

ELECTRICAL EQUIPMENT

The following general guidance applies to the design and operation of electrical devices:

- All equipment should be properly insulated.
- Consideration should be given to the heating effects of the electrical circuits.

- All splices and joints and the free ends of conductors should be covered with an insulating device suitable for the purpose.
- Parts of electrical equipment which, in ordinary operation, produces arcs, sparks, flames, or molten metal should be enclosed or separated and isolated from all combustible material.
- Equipment should be properly labeled with information to do with the manufacturer, voltage, wattage, and other ratings.
- Each service, feeder, and branch circuit should be legibly marked to indicate its purpose.
- Each means for disconnecting motors and appliances should be legibly marked to indicate its purpose, unless located and arranged so the purpose is evident. These markings should be durable.

Electrical equipment in process facilities is often exposed to rain and process fluids. Therefore it is important to use Ground Fault Circuit Interrupters (GFCIs) in these situations. These are devices that will trip and disconnect a circuit when the leakage current to ground exceeds approximately 5 milliamps—below any personnel hazard level. The speed of response generally is less than 0.05 seconds for 15−20 amp units. GFCIs should be used for the following applications:

- All 120-volt single-phase 15 and 20 amp outlets that are not part of the permanent wiring of a building or structure (e.g., temporary wiring during construction)
- Washroom and change room outlets
- For all areas with moist or wet ground where electrical equipment or portable electric tools are likely to be used
- Areas where portable electric tools are used regularly, such as in plant shops, or during maintenance

CHAPTER

Piping and valves

13

CHAPTER OUTLINE

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00013-5

INTRODUCTION

Many of the general comments made with respect to the safety and operation of pressure vessels apply equally to piping and valves. Indeed, a pipe is, in effect, a pressure vessel. Also piping, valves and flanges must meet the requirements for safe operation at operating temperatures and pressures, and must be chemical resistant to the liquids and gases that go through them.

PIPING

When designing, operating, and maintaining piping issues to consider include materials of construction, insulation, and the selection of gaskets.

MATERIALS

Steel piping is widely used due to its strength, flexibility, ductility, and weldability. However, steel may not be practical for some acids, chemicals, or for use at high temperatures. Seamless steel pipe affords maximum fire safety. Steel is often used in lines carrying water or steam where failure at times of fire could interfere with firefighting activities. Steel should also be used for valves, flanges, and fittings, because of its superior ability to tolerate thermal shock, bending loads, and hydraulic/mechanical shock.

Welded joints in steel and steel alloys are more likely to remain tight through a fire than any other type. In large-size pipes, welded joints cost less than screwed or flanged joints and should be used in all cases except where the installation of slip blinds requires the availability of flanges.

Cast iron is less expensive and in some cases more corrosion resistant than steel. Nevertheless, the use of cast iron pipe is undesirable in oil or gas service because of its brittleness. If heated by fire exposure and then quenched it can fail.

Rubber, neoprene, plastic, aluminum, brass, and other low melting point materials should not be used for hydraulic or lube oil piping. A small fire near these materials will cause them to fail quickly with the potential to release large volumes of oil into the fire.

Piping made of brass, copper, or aluminum is sometimes used for special purposes. These metals have low melting points and thus have a high potential for failure if exposed to fire. Alloy materials are sometimes chosen for severe temperature or corrosion services.

INSULATION

Pipe insulation should be noncombustible. Where hot piping insulation can be exposed to hydrocarbon leaks it should be provided with metal weather jacketing because oil soaked into the insulation can autoignite at line temperatures as low as 175°C.

GASKETS

For the majority of moderate-temperature services, composition gaskets on raised face flanges are acceptable. At flanged joints where additional reliability is desired or for higher temperatures, spiral-wound gaskets on raised face flanges should be used. For services with special temperature, pressure, or chemical hazard problems, a ring-type joint or equivalent should be considered.

THREADED PIPING

Threaded piping has the following weaknesses and should not therefore be used in sizes larger than 2″ or smaller than ¾″ in hydrocarbon or critical utility service (with the possible exception of low-temperature or low-pressure services in low risk areas):

- Weakness resulting from the notch effect at the root of the thread, which is a point of stress concentration
- A decrease in effective wall thickness where the threads are cut
- Susceptibility to thread disengagement by expansion when exposed to fire
  Susceptibility to vibration and fatigue failure

THERMAL EXPANSION

Hot process lines need to be able to handle thermal expansion; even with lines expected to operate at normal temperatures it is desirable to provide sufficient flexibility for expansion and contraction caused by changes in atmospheric temperature, possible fire exposure, steam out, and pump out. Flexible couplings may fail rapidly under fire exposure and should be avoided wherever possible in systems handling hydrocarbons. The use of offsets in welded pipe is much safer.

Provision should be made to relieve excess pressure developed in lines due to the thermal expansion resulting from temperature changes. Relief valves should be installed on all lines that can be blocked and where no valve leakage is expected, and on lines confined by valves where leakage past the valve can be expected, but where there is more than around 60 meters of pipe per valve.

IDENTIFICATION AND LABELING OF PIPES

Piping that is either partially or wholly exposed should be identified by legends that include the safety color code, pipe contents, flow direction arrows, and to/from information.

TESTING AND INSPECTION

Representative test, inspection, and repair methods for piping and valves are shown in Table 13.1.

BLINDS

Blinds—also known as blanks or spades—Blinds provide positive isolation between sections of a process. The following guidance is provided to do with the location, installation, and use of blinds:

- At battery limits in all process, utility, relief, and blowdown lines
- As required for inspection, maintenance, testing, or alternative operation of equipment, such as vessels, heaters, rotating equipment, or exchangers
- Where segregation of fluids is required
- Blinds should be installed in horizontal lines where possible. Doing so makes handling and installation easier and reduces the chances of damaging the gaskets during installation. Also, blinds in vertical lines may trap liquid above them. For this reason, blinds should not be used in vertical water or steam lines where there is a potential for freezing
- Blinds for rotating equipment and the tube side of shell-and-tube heat exchangers should not be located at the equipment flanges
- Piping at locations where blinds and their associated spool pieces should be arranged so as to permit the removal of the bolting for the blinds, and to allow

Table 13.1 Test, Inspection, and Repair Methods for Piping and Valves

Program Element	Program Requirements
Design Basis/Requirements	ASME/ANSI B31.1, B31.3
Inspection/Test Procedures	Inspection API-570
Inspection/Test Frequencies	Inspection API-570 and operating experience
Inspection/Test Acceptance Criteria	ASME/ANSI B31.1, B31.3
Repair and Alteration Procedures	API-570

space for swinging the blind once it is unbolted. Sufficient space should be provided not only to insert the blind but also for the equipment needed to lift the blind into place

- Supports to maintain piping alignment when blinds are being installed or removed are required if the piping or other items, such as valves, are located at or near the blind location
- When it is expected that a blind will be inserted and removed on a regular basis, platforms should be provided
- Permanent handling equipment shall be provided for all blinds weighing more than 45 kg (100 lb).

Most blinds are either of the line or spectacle type.

LINE BLINDS

A line blind—also known as a spade, paddle, skillet, pancake, or slip blind—consists of a solid metal disk with a thin length of metal attached to it. The metal of the blind should be rated for full process pressure on one side and atmospheric pressure on the other side. The handle should be long enough so that it can be seen through insulation and any other materials that might be covering the flange.

SPECTACLE BLINDS

If a flange is to be routinely blinded, a spectacle blind (also known as a Figure 8, disk-and-donut, or spec blinds) can be installed. This type of blind looks like a pair of spectacles or the number 8, with one section closed and the other open. When the flange is broken and the line cleared, the blind can be rotated around the one bolt that is left in the flange. It is simple to ensure that the blind has been installed because the open part of the blind will be sticking out from the flange face.

If spectacle blinds in horizontal pipes are insulated, the blind should point downwards at an angle of 45° to avoid water leaking into the insulation.

VALVES

Valves are used to stop and/or control the flow of fluid in piping systems. The different types of valve and their uses are discussed below.

BLOCK VALVES

Block valves are, as their name suggests, valves that are used to totally stop the flow of liquid or gas through a pipe. They are generally either open or closed and should not be used to control the flow of fluid. They can be either manually operated or, in the case of large valves, opened with a motorized assist.

Different types of block valve include gate, ball, butterfly, plug, and needle valves.

VALVE SEAT MATERIAL

When exposed to fire, rubber-like, or Teflon materials used for sealing, valve seats will fail faster than the valve metal. Therefore, all ball valves, plug valves, and valves that depend on O-ring stem seals in liquid hydrocarbon service should be designed so that failure of the seat material will not cause more than minor leakage past the ball, plug, or stem.

SELF-CLOSING VALVES

Self-closing valves are used where failure to close a valve manually might permit flow of oil or gas into areas where a serious fire may result. The types of installation for which self-closing valves should be considered include water and chemical draws, vents, bleeders, drains, level cocks, sample points, and tank truck and barrel filling and emptying systems.

CHECK VALVES

A check or nonreturn valve is a commonly used safeguard to prevent the fluid backflow. It is, however, liable to failures such as the following:

- Solid deposits wedge themselves into the check valve's mechanism such that it does not close on demand
- Corrosion products prevent the flapper from closing
- The flapper fails to seat properly, thus allowing some leakage.

For these reasons, check valves are normally regarded as being only a weak safeguard and should not be relied upon in critical service. As one hazards analysis leader has said "If you rely on a check valve to be safe, then you're not safe." Another leader uses a figure of 49 in 50 for check valve reliability in clean service, i.e., he anticipates that a check valve will not work on demand 2% of the time.

EMERGENCY ISOLATION VALVES

If there is a serious fire on a unit, it may be impossible for the operators to reach the valves that must be closed to stop additional flammable material from feeding the fire. Therefore, it is useful to have emergency isolation valves (EIVs) at the unit's perimeter. If these valves are closed, the flow of all hazardous chemicals into the unit will be stopped and the fire will go out once the inventory of material within the unit has been consumed. The EIVs must be located and protected such that they are not damaged in a fire or explosion, and operators can reach them in an emergency. EIVs can be either manual or automatic. If they are

Table 13.2 Representative Test Pressures

Valve Component	Hydrostatic Test Pressure
Nozzles, both full and semi, bodies for semi nozzle valves, bodies with integral nozzles, primary pressure containing components of pilot-operated main valve	1½ times the maximum allowable design pressure per the manufacturer's catalog
Bodies for valves with full nozzles, closed bonnets with caps	1½ times lower of the maximum outlet flange rating pressure or maximum allowable back pressure per the manufacturer's catalog
Bellows for balanced type valves	Minimum of 30 psig (210 kPa)
Primary pressure containing parts of pilot valves	1½ times the maximum inlet flange rating
Exterior of bellows	Manufacturer's published maximum pressure limit

automatic it must also be possible for the operators to reach them in an emergency and to close them by hand.

Table 13.2 provides representative hydrostatic test pressures for various valve components.

EXCESS FLOW VALVES

Excess flow valves shut when the flow rate exceeds design flow rates. They are frequently used on hoses. However, they are not generally used emergency shutdown or on storage vessels, loading points, or multi product systems, since they are not sufficiently reliable.

TRAPPED LIQUIDS

Valves used in hydrocarbon liquid service should not trap liquids in their bodies. The liquid could expand during a fire and overpressure the valve body. Standard gate valves are normally not a problem because excessive pressure can be relieved by minor leakage past the valve seat. However, valves such as the "double-block and bleed" type will trap liquid. When these valves are used in liquid service, body relief valves are needed.

PLUGS

Steel plugs should be installed in all open-ended valves when not in use. Vents and drains should be routed away from the pump. In clean services, restriction orifices can be installed on root valves under pressure gage and pressure transmitter connections to minimize the release if damage to the gage or pressure lead occurs.

Plug cocks have been known to trap liquid inside the plug and bonnet area and cause potentially serious releases during maintenance.

PRESSURE RELIEF DEVICES

Pressure relief systems usually represent the last line of defense. This means that these systems should never actually be called upon to operate—high-pressure events should be handled by other safeguards in the lead-up to the event. But, if the pressure relief system *is* needed, then it *must* work. Hence the quotation "Relief valves must always work; relief valves should never work." For this reason many companies require that, if a pressure relief valve opens during a high-pressure excursion, then a full incident investigation must be carried out since the last line of defense had to be used.

DESIGN PARAMETERS

The following types of pressure relief device are discussed in this section:

- PSRV
- Thermal relief valves
- Rupture disks
- Hatches

REGULATIONS AND STANDARDS

Because relief valves are so critical to safe operations, many standards and rules have been written to do with their design and operation. Table 13.3 lists some of these standards and provides a brief description of their contents.

The design of relief valves for complex, two-phase flow systems is discussed in the DIERS literature from the Center for Chemical Process Safety.

Causes of a relief valve not opening at its set pressure can include corrosion of the internals or plugging of the valve inlet or outlet with deposits.

PRESSURE SAFETY RELIEF VALVES

Pressure safety relief valves (PSRVs), the symbol for which is shown in Figure 13.1, frequently cross systems boundaries, *i.e.*, they protect more than one process section. The scenarios to consider for isolation here are: when the equipment the PSV is protecting needs to be worked on or the PSV itself needs to be removed and worked on. Each PSV will have an isolation valve both upstream and downstream of the PSV.

Table 13.3 Pressure Relief Devices Standards

Publication	Title	Comments
API RP 520 Part 1 (2000)	Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries—Sizing and Selection	Although this standard is directed toward refineries, it can be used for guidance in other applications
API RP 520 Part 2 (2003)	Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries—Installation	
API RP 521 (2008)	Guide for Pressure-Relieving and Depressuring Systems	This recommended practice provides guidelines for examining the principal causes of overpressure; determining individual relieving rates; and selecting and designing disposal systems, including such component parts as vessels, flares, and vent stacks
API STD 526	Flanged Steel Pressure Relief Valves	
API STD 527	Seat Tightness of Pressure Relief Valves	
API RP 576	Inspection of Pressure-Relieving Devices	
API STD 2000	Venting Atmospheric and Low-Pressure Storage Tanks Nonrefrigerated and Refrigerated	

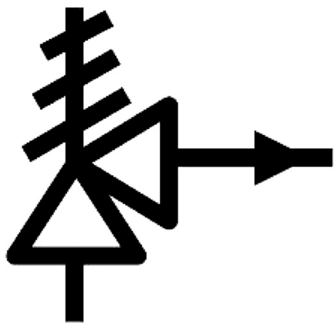

FIGURE 13.1

PSRV symbol.

When the equipment the PSV is protecting needs to be worked on, the pressure will be bled off the equipment and both upstream and downstream PSV isolation valves will be closed, the piping bled off, and a spade will be installed ahead of the upstream PSV isolation valve. The same procedure applies where there are dual PSVs in parallel.

When the PSV needs to be removed and worked on, the equipment the PSV is protecting will be shut in, both PSV isolation valves will be closed, the equipment will be depressurized, the PSV removed, and blinds installed on both open ends of the isolation valve flanges. Where 100% online capacity can be maintained while working on a parallel PSV, and the PSV can be safely isolated (risk assessment performed), shutting in the equipment, and depressurizing is not required.

The PSVs themselves are not considered as isolation valves for system or component isolation.

PSRVs are the primary source of protection against overpressure for equipment used in the process industries and are to be found on virtually all pressure vessels. They provide a passive solution to high pressure caused by events such as blocked outlet from the equipment, external fire, and failure of cooling water. Generally, PSRVs are required for pressure vessels having a maximum allowable working pressure (MAWP) above 1 barg. The design of relief valves for complex, two-phase flow systems is discussed in the DIERS literature from the Center for Chemical Process Safety. The sizing of pressure relief valves does not normally take credit for instrumentation (including safety instrumented systems or SIS), emergency shutdown systems, or any form of human intervention.

When protecting a column that has a reboiler, condenser, and overhead reflux drum, a single relief valve is frequently used, as long as there are no block valves or other means of creating flow restrictions between the equipment items. (The heat exchangers may need their own relief valve on the utility side if a hazards analysis shows that a leak from the process into the utility stream could cause unacceptable overpressure.)

Some process operations use operating relief valves as part of their normal operation, often in batch processes. For example, a chemical reaction may generate increasingly high temperatures and pressures. When the internal pressure rises above a certain point, the relief valve opens and the system pressure is reduced. In such situations, the relief valve is not a true safeguard because it is probably not as reliable as a true PSRV and it may not have been designed for the worst case scenario.

When designing a PSRV, all possible high-pressure scenarios such as external fire and runaway reaction should be considered. In general, the "single event" concept should be used. This means that only one emergency (or group of interrelated emergencies that develop from a single fundamental cause) will occur at one time. In other words, it is assumed that only one emergency (or group of interrelated emergencies that develop from a single fundamental cause) will occur at one time. This event constitutes the basis for design. The probability that multiple unrelated incidents would occur simultaneously is so low that it need not be considered. Moreover, the size and cost of safety facilities would be excessive if they were designed to handle every conceivable emergency and to handle them all simultaneously.

But it is important to watch for common causes of seemingly independent events. For example, electrical power failure could cause both low flow out of a vessel and an uncontrolled chemical reaction.

The worst case is selected for the design of the relief device.

In addition to complying with local and environmental requirements, relief valves discharging directly to the atmosphere should meet the following good fire and safety practices:

- Only noncondensable vapors should be discharged to atmosphere.
- Discharge point of atmospheric releases must be located and oriented so that flammable concentrations do not reach ignition sources.
- Ignition of the effluent would not expose adjacent equipment or personnel.
- The vapor must not be toxic.
- The velocity of discharge at rated capacity should not exceed 30 m/s.
- Discharged materials should be directed upwards, away from personnel or equipment.
- Stacks should be at least 1 m above the vessel and 6 m above grade.
- Stacks should extend 3 m horizontally from mechanical equipment.
- They should be properly supported and braced, with no caps, bends, or obstructions in the discharge path.
- Drain holes must be provided at the low point of the discharge stack to prevent liquid or ice accumulation in the relief valve discharge. The drain opening should be directed away from equipment and piping to prevent impingement by any flame that may come from the hole.
- Piping should be limited to a single ell or an ell and short nipple to minimize risk of plugging.
- Where vent stacks on hydrocarbon relief valves are susceptible to ignition by lightning, the use of snuffing steam should be considered.
- Pressure relief valves capable of venting liquids should discharge through a separator or flare drum so that the liquids are recovered, and also to prevent the liquids falling to the ground and a potential source of ignition.

PILOT-OPERATED PRESSURE RELIEF VALVES

The disk in a normal relief valve is kept in the closed position during normal operations by the force of a spring. A pilot-operated relief valve (PORV), however, uses system pressure to seal the valve as shown in Figure 13.2.

Figure 13.2 shows a small control pilot valve attached to the relief valve. The pilot valve allows the pressure in the dome to be equalized with the main system pressure. The area of the top of the piston in the dome is greater than the area on the system side so, even though the pressures on each side are the same, the downward force is greater than the upward force so the piston is held in place. If the system pressure rises above the safe limit the pilot valve opens and allows the

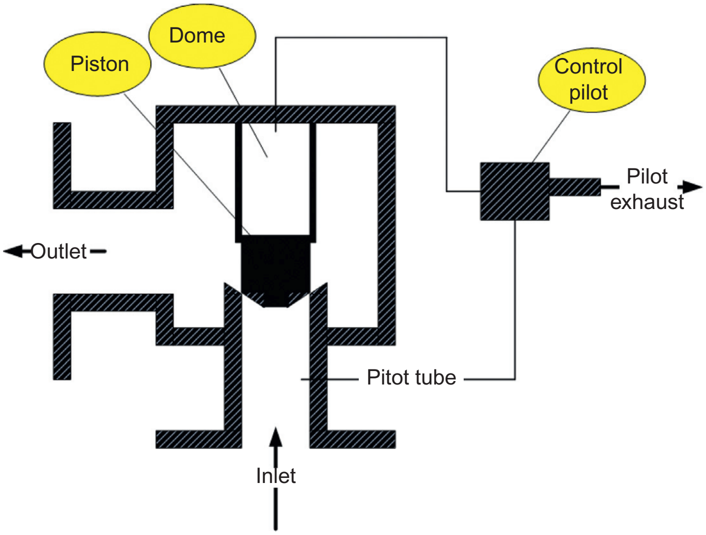

FIGURE 13.2

Pilot-operated relief valve.

gases in the dome to be vented to atmosphere or a relief header. The piston then opens and system gases flow out of the vessel being protected. To prevent excessive forces on the discharge piping, the pilot can be designed to open gradually such that the piston lifts in proportion to the degree of over pressure.

PORVs have the following advantages over standard pressure relief valves:

- For larger pipe sizes the relief system is smaller
- There are more options for control
- The system seals more tightly when system pressure approaches, but does not exceed set point pressure

However, they tend to be more expensive for small valve sizes and the pilot valve is sensitive to contaminating particles (a filter screen should be provided on the inlet to each pilot).

THERMAL RELIEF VALVES

Thermal relief valves are found in services where a system, such as a long length of pipe, is liquid full and is subject to the heat of the sun or some other low intensity heat source. Thermal relief valves are also used for low or ambient temperature pumps that can be blocked in.

Thermal relief valves are generally small because they only need to relieve a small amount of liquid in order to bring the system to a safe operating pressure.

DISCHARGE PIPING

The discharge from a relief valve can go directly to the atmosphere or to a flare/blowdown header. If it goes to the atmosphere, the following guidelines should be considered:

- Only noncondensable vapors should be discharged. (Pressure relief valves capable of venting liquids should discharge through a separator or flare drum so that the liquids are recovered, and also to prevent the liquids falling to the ground.)
- Discharged materials should be directed upwards, away from personnel or equipment.
- Ignition of the effluent must not expose adjacent equipment or personnel.
- The discharge point must be located and oriented so that flammable concentrations do not reach ignition sources.
- Where vent stacks on hydrocarbon relief valves are susceptible to ignition by lightning, the use of snuffing steam should be considered.
- The vapor must not be toxic.
- The velocity of discharge at rated capacity should not exceed 30 m/s.
- Stacks should be at least 1 meter above the vessel and 6 meters above grade.
- Stacks should extend 3 meters horizontally from mechanical equipment or 2 meters above the highest platform within a 3-meter radius of the vent outlet. They should be properly supported and braced, with no caps, bends, or obstructions in the discharge path.
- Drain holes must be provided at the low point of the discharge stack to prevent liquid or ice accumulation in the relief valve discharge. The drain opening should be directed away from equipment and piping to prevent impingement by any flame that may come from the hole.
- Piping should be limited to a single ell to minimize the risk of plugging.

Generally, the outlet pipe is larger than the inlet pipe. The following ratios frequently apply:

- 2 inches × 3 inches (51 mm × 76 mm)
- 3 inches × 4 inches (76 mm × 100 mm)
- 4 inches × 6 inches (100 mm × 150 mm)
- 6 inches × 8 inches (150 mm × 200 mm)
- 8 inches × 10 inches (200 mm × 250 mm)

When protecting a column that has a reboiler, condenser, and overhead reflux drum, a single relief valve is frequently used, as long as there are no block valves or other means of creating flow restrictions between the equipment items. (The heat exchangers may need their own relief valve on the utility side if a hazards analysis shows that a leak from the process into the utility stream could cause unacceptable overpressure.)

When a safety relief valve opens, it can place considerable mechanical stress on the pipework that supports it. This topic is discussed in detail by White and Smith (2013).

TESTING AND INSPECTION

All relief valves must be inspected on a regular basis. Indeed, such inspections are often mandated by regulation, e.g., for boiler service. Generally, the relief valve is removed from the vessel that it is protecting and tested in a workshop. The test will ensure that the relief valve opens at the specified pressure. Ideally, the test should also check the volumetric capacity of the valve. During the test, an inspection should be carried out to check for corrosion, physical damage, and any other problems that could affect the integrity of the relief valve. A representative testing is shown below:

- 30% annually
- 60% every 2 years
- 10% on an individual schedule

Representative test, inspection, and repair methods for vent and relief systems are shown in Table 13.4.

The following list provides an example of guidelines used for testing relief valves:

- Components of pressure relief valves should be hydrostatically tested before assembly. Parts made from forgings or bar stock are exempt.
- A specific inspection frequency shall be established for each safety relief valve. The inspection frequency will be a function of inspection history, relief system design, process conditions, operating experience, on-stream service capabilities, economics, and regulatory mandates.
- The maximum interval between inspections shall not exceed 10 years.
- The interval between inspections may be increased (not to exceed 10 years) based upon observed conditions at the time of shop inspection, engineering review, and reliability improvements.
- If a rupture disk is installed to isolate the relief valve from a particularly corrosive process, and the integrity of the rupture disk is known to be good, the interval between inspections may be increased. The rupture disk integrity must be verified via checks for pressure between the rupture disk and relief valve.
- If the relief valve has bellows to isolate the spring and close clearance parts from the downstream process, and the integrity of the bellows is known to be

Table 13.4 Test, Inspection, and Repair Methods for Vent and Relief Systems

Program Element	Program Requirements
Design Basis/Requirements	ASME, API 520, API 521, API 530, API RP 537
Inspection/Test Procedures	NBIC (National Board Inspection Code), API-510, operating experience
Inspection/Test Frequencies	Operating experience
Inspection/Test Acceptance Criteria	Manufacturer’s recommendations
Repair and Alteration Procedures	Manufacturer’s recommendations

good, the interval between inspections may be increased. The bellows must be vented in normal operation (at atmospheric pressure). The integrity of the bellows must be verified via on-stream bellows testing.

- If a purge medium is used to minimize exposure of the relief valve internals to process fouling or corrosion, the interval between inspections may be increased.
- If materials of construction are selected such that corrosion will have minimal effect on the spring and valve trim, the interval between inspections may be increased.
- The interval between inspections must be decreased when service records indicate that the relief valve was heavily fouled or inoperative at the time of the last inspection or test.
- An online test may be used as the basis for extending the inspection interval to coincide with a planned outage provided the valve pops and resets at the proper settings. However, online testing cannot be substituted for a regular shop inspection and repair, nor can it be used as the basis for a permanent increase in the inspection interval.
- A relief valve must be removed from service for inspection and repair after an online test if it fails to open at set pressure or the valve chatters, or if it fails to reseat properly.

RUPTURE DISKS

A stand-alone rupture disk can be used in preference to a pressure relief valve in the following circumstances:

- *Reduced capital and maintenance costs*

  Rupture disks are cheaper than relief valves and do not require ongoing maintenance and routine pressure testing. After a high-pressure release, a rupture disk simply needs to be replaced whereas relief valves need to be reset and tested.
- *When loss of the system contents through the vent lines is not important*

  A rupture disk does not close when the system pressure returns to normal. Hence, the entire contents of the system can be lost. If the vented material is of high value, or if the material could cause problems downstream in the vent or flare systems, then a relief valve is probably the better choice. Otherwise, a rupture disk is satisfactory.
- *Fast response*

  Rupture disks are extremely fast acting, and so should be considered when there is a potential for runaway reactions. In such situations, relief valves may not respond quickly enough to prevent a catastrophic failure.
- *The vented material is a viscous liquid*

  If the system is filled with highly viscous liquids such as prepolymers, a rupture disk should be considered as the relieving device. Flow through a relief valve will be very difficult to calculate accurately. Also, very viscous fluid may not relieve fast enough through a relief valve and may even cause it to plug.

Rupture disks may be placed below relief valves for the following reasons:

- To ensure a positive seal of the system. If the relief valve could leak, a rupture disk below it will help ensure that the system remains contained.
- The system contains solids that may plug the relief valve over time. This can be particular problem with equipment containing monomer vapors such as styrene. Without a rupture disk, the vapor can condense around the relief valve internals; the condensed liquid then polymerizes and gradually plugs up the internals of the relief valve. The problem is exacerbated because it can be difficult to inject polymerization inhibitor into the relief valve mechanism. The performance of a rupture disk, however, is not likely to be materially affected if it is coated with a thin layer of polymer.
- If the process materials are corrosive, the rupture disk is specified with the more exotic and corrosion resistant material—the relief valve can be fabricated from lower cost materials.

One potential problem with the use of rupture disks below relief valves concerns the possibility of pinhole leaks in the rupture disk. If such a leak occurs, then the pressure on the downstream side of the disk will be roughly equal to the process pressure. Therefore, the absolute process pressure required to rupture the disk may be almost twice as high as expected. Moreover, the existence of the pinhole leak may lead to the development of the problem that it was intended to avert, e.g., the relief valve could be plugged with polymer without anyone being aware of the situation. Because of the dangers associated with pinhole leaks, it is good practice to install a pressure gage in the spool piece between the rupture disk and the relief valve.

HATCHES/DOORS

In low-pressure systems, particularly those that do not contain toxic or highly flammable materials, pressure relief can be provided by hatches or doors. If the pressure becomes too high, the hatch or door flies open. There are, however, a number of issues to watch for with such systems, including ensuring that the hatch or door is properly restrained (often with a hinge) so that it does not fly through the air, and then ensuring that, when the pressure returns to normal, the door or hatch does not close too quickly. If it were to do so, a vacuum condition might be created. Also, of course, it is vital that no one be allowed to stand on the hatch or adjacent to the door.

FLAME ARRESTORS

A flame arrestor is installed just upstream of a pipe vent when it is possible that the material being vented could catch fire and then send a flame front back down the pipe into the equipment below the vent tip. This backward movement can occur when the mixture is in the flammable range but the velocity at the open end exceeds the flame propagation velocity. If the flame does travel backwards it can gain velocity, eventually reaching supersonic or detonation speeds.

Any gas disposal or gas handling system that feeds the gas stream into a flare, furnace, incinerator, or other high temperature disposal system should have flame arrestor protection. Examples are as follows:

- Flares between the pilot flame and the incoming flow
- Vapor recovery systems for ship, truck, and railcar loading to protect the recovery equipment from internal system ignition sources and external on-site ignition sources
- Miscellaneous process plant waste gases that are incinerated in furnaces or on-site incinerators should have flame arrestors in the waste gas line near the incineration point.

If the vented material has a high concentration of hydrocarbon such that it is too rich to burn, then a flame arrestor may not be needed. (Adding fuel gas to a vent stream such that the vent stream becomes too rich may can avoid the need for a flame arrestor.)

Steel cone roof storage tanks equipped with pressure-vacuum-type breather valves do not generally need flame arrestors. The vapor space will generally be either too rich or too lean to allow for the creation of a flammable mixture at the vent discharge. (Also, the likelihood of there being an ignition source at the same time as the tank is venting is low.) Moreover, putting a flame arrestor under a breather valve is not recommended because of the need for additional maintenance to prevent clogging, plugging, or freezing of the arrestor. This can cause a tank to collapse by vacuum if products are being pumped out.

THERMAL FLAME ARRESTORS

Thermal arrestors employ a cellular heat-absorbing medium to stop the flame advancing by absorbing the heat of combustion, while at the same time permitting gas or vapor to flow through it. Cooling is accomplished by combining a small passageway for the flow of fuel and a large amount of heat-absorbing material. Heat is absorbed by the metal plates or tubes, lowering the temperature of the vapor below its ignition temperature so that it no longer supports combustion. Other thermal-type flame arrestors use multiple layers of screens or perforated metal plates, bundles of short metal tubes, alternating layers of crimped and flat metal sheets, and packed spherical pellets of metal.

If fuel flow through the arrestor is not safely stopped and the condition allowing the flame to burn at the arrestor is not corrected, the flame will continue to burn at the face of the heat-absorbing surface in the arrestor, eventually raising the temperature of the flame arrestor medium and its enclosure such that it might ignite the flammable mixture on the downstream side of the arrestor.

Potential problems with thermal flame arrestors include the following:

- Failure to arrest flames if not installed in conditions similar to the ones for which it was tested and approved.
- Clogging of arrestor elements from deposits formed by vapors when they come in contact with air or by solid materials carried by the gas stream.
- Freezing of moisture condensation in the arrestor elements.
- Reduced flow capacity of the system due to the large pressure drop across the arrestor element.
- Failure of the small gas or vapor passages due to corrosion or mechanical damage.

DETONATION ARRESTORS

Detonation arrestors are essentially heavy-duty thermal-type flame arrestors designed to handle the peak overpressures of a detonation. These would only be used in those systems where the criteria for distance from the atmospheric outlet or ignition sources cannot be met.

WATER SEAL-TYPE FLAME ARRESTORS

This device employs a water seal in which a gas stream bubbles through the liquid. Gas distribution is important to prevent channeling of the stream and to maintain the flow as a stream of individual bubbles. Therefore, the gas inlet connects to a distribution pipe drilled with rows of holes or vee notches below water level to form the water seal.

The water seal-type arrestor is most suitable for installation in systems where the following conditions prevail:

- The flow is only in one direction
- There is a reliable flowing water supply to assure the seal is not lost
- The allowable pressure loss through the arrestor is at least several inches of water
- Freezing of the seal will not occur

The seal at the base of flares is often of this type.

VELOCITY-TYPE FLAME ARRESTORS

The velocity flame arrestor works by ensuring that the velocity of the flammable mixture is higher than the velocity of flame propagation through the mixture. The flame arrestor is typically installed about 30 pipe diameters or 5 meters upstream of the vent tip.

When the gas flow velocity falls to near the flashback velocity, steam can be added to the stream, thus increasing flow velocity and also inerting the flowing mixture. Velocity flame arrestors usually consist of a venturi-type tube provided with a steam nozzle located close to the throat or steam ports in the throat of the tube (media other than steam can be used if they are equally effective and more economical).

Velocity flame arrestors must not be too far from the ignition source, otherwise the flame that is traveling backward may accelerate such that its velocity is sufficient to pass through the arrestor.

The velocity-type arrestor is most suitable for installations where the following conditions apply:

- Gases or fumes are to be burned in a waste disposal furnace
- Flow is in one direction only
- Flow rate is normally constant
- Allowable pressure loss through the arrestor is low

FLARES

Flaring is the process of disposing of unwanted flammable gases and vapors by combustion into the open atmosphere. The gas is sent along a flare header, mixed with air, and burned at a flare tip. The unwanted gas must be flammable or inert, and must not create hazardous or environmentally sensitive products after it has been burned.

ENGINEERING STANDARDS

Two widely used standards for the design and operation of flare systems are API 521—*Guide for Pressure-relieving and Depressuring Systems: Petroleum Petrochemical and Natural Gas Industries* and API 537—*Flare Details for General Refinery and Petrochemical Service*.

TYPES OF FLARE

There are three types of flare: continuous, intermittent, and emergency. A continuous flare is one that is operating virtually all the time. A common example of this type of flare is to be found at oil wells in remote locations. The oil usually contains dissolved hydrocarbon gases. As the oil is brought to the surface, the reduction in pressure causes the gases to come out of solution. Since it is frequently uneconomical to process this associated gas, it is sent to a flare. Also, continuous flares are often used at chemical plants and refineries that have a low-pressure gas stream to dispose of.

Intermittent flaring often occurs at facilities during maintenance activities. For example, if a compressor has to be worked on then the gases to its suction will be diverted to the flare. Similarly, if it is necessary to enter a vessel for inspection its contents will be sent to flare before being replaced with air.

Emergency flares handle a situation where all or most of a facility has to be blown down quickly due to an event such as a runaway reaction, fire, or a large leak of toxic materials.

SMOKELESS OPERATION

It is important to achieve smokeless operation for environmental reasons. In order to achieve this goal, the flare design should consider use of the following:

- Multistage flares which can handle large swings in flow
- The correct choice of flare tip
- Pressure-assisted flares use the energy from the vent stream's pressure to promote mixing within the burner tip
- Knock-out drum—located at or close to the base of the flare—to remove any liquids present in the vent stream or that may condense out in the collection header and transfer lines. Liquid in the vent stream can extinguish the flame or cause irregular combustion and smoking; flaring liquids can generate a spray of burning chemicals that could reach ground level and cause a fire
- Sonic flares. These cause the flaring gases to go through the multiple tips at the speed of sound. The effect of this is to cause high turbulence in the gas stream, which causes excess quantities of air to enter the burners.

LOCATION OF FLARES

Most flares are elevated, usually to an extent that it is one of the most prominent features of a refinery or chemical plant. However, many flares—"pit flares"—are located at grade with fencing around them to prevent people from approaching them too closely. The following considerations apply to their location.

- Spacing of elevated flares from process equipment or facility boundary depends on the flare stack height, flare load, and the allowable radiant heat intensity for personnel, public, and equipment.
- Flare stack locations should be provided with a sterile area.
- The flare should be located to minimize the potential for ignition of vapor released from the process units.
- Where burn pits or flares at grade are provided, a minimum spacing of 150 meters should be provided to equipment containing hydrocarbons or to the plant boundary.

Offshore, the flare boom or tower and/or high pressure, cold vent stacks should be located downwind of the Safe Area. Also, flare and vent systems should be designed and located to the extent practical to prevent liquid carryover onto the platform or on normal boat or barge traffic areas.

CHAPTER

Safety instrumentation

14

CHAPTER OUTLINE

INTRODUCTION

Modern process facilities are highly instrumented. The instruments are used to:

- Monitor on-going process conditions.
- Provide information to the operating technicians.
- Adjust operating variables.
- Take corrective action should process conditions move outside the safe range through the use of alarms, interlocks, and trips will all bring the system back to a safe state.

The words *interlock* and *trip* are often used interchangeably, but strictly speaking, they have different meanings. An interlock prevents an action from being taken, whereas a trip causes an action to be taken. Interlocks are commonly found on hazardous systems such as oxygen mix stations. They prevent oxygen from being added to the system unless the correct concentration of hydrocarbon is present. Pig launcher doors, relief valve isolations, and blowdown valves are also often provided with interlocks.

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Trips shut down systems that are already in operation. For example, a high temperature trip on a furnace will shut off all the burners when temperatures get too high. Trips can be activated either automatically or by operator action.

Broadly speaking, safety instrumentation falls into two categories: safety instrumented systems (SISs) and high integrity protection systems with its subset of high integrity pressure protection systems (HIPPSs) that are used to protect specifically against overpressure.

ALARMS

An alarm (usually in the form of a buzzer and/or flashing signal on the control panel) tells the operators that the system is either in an unsafe condition or is moving in that direction. Safe limits, as defined by the process safety program, provide potential values for alarm values. One is hi and the other hi-hi. There are also corresponding lo and lo-lo values. The hi alarm warns that an unsafe condition is developing but that the operator has time to think through as to what actions to take. A hi-hi alarm means that the situation has become serious, and immediate action is needed.

Some facilities have operations alarms that do not have an explicit safety purpose. For example, an operator may be preparing a solution of polymerization inhibitor. The recipe for this may change from batch to batch. If the tank for a particular batch is to be filled to say the 65% level, the operator can set the alarm at that value, start filling the tank and then move on to some other activity. When the alarm sounds, he or she will stop the fill process. If the next batch requires a 75% level, the operator can adjust the alarm correspondingly.

ALARM DESIGN

Guidance to do with the design of alarm systems is provided below.

- The alarm should be clearly audible above the location's normal ambient noise levels.
- Different types of alarm can indicate different types of emergency and action need.
- All operating technicians should know how to manually create an alarm signal.
- The alarm's manual activation devices shall be easily accessible and clearly identified as to their purpose.

ALARM MANAGEMENT

The advent of distributed control systems (DCS) makes it easy to add alarms to cover every possible operational deviation. However, too many alarms cause a situation called *alarm flooding*, whereby operators do not know which ones to pay attention to. For this reason, it is important to control the number of alarms, and ensure that the operators know which alarms were the "first out," i.e., which alarms were triggered first before the others followed in a cascade. Other potential problems to do with alarm management include the following.

- *Standing alarms.* These never go away, no longer mean anything, and are ignored. They waste display space on the console and reduce confidence in the value of the alarm system.
- *Chattering alarms.* These start, reset, and start again—often repeatedly. They are distracting, fill up alarm summaries, and—once more—reduce confidence in the value of the alarm system.
- *Meaningless alarms.* These are alarms that are no longer important but remain active. They are distracting and minimize the operators' sense of urgency.
- *Disabled alarms.* These alarms may have been disabled for reasons such as those listed above but they may be needed in the future.
- *Poorly prioritized alarms.* Only true emergency alarms should be given high priority so that operator attention during an emergency is not diluted.

A general rule is that there should be no more than one alarm every 10 minutes during steady operation, and no more than one alarm per minute during an upset.

In order to overcome some of the problems just listed, Jofriet (2005) proposes a six sigma-based approach to alarm management using the following steps:

- Establish the desired alarm philosophy
- Assess the performance of the existing alarm system
- Set alarm performance benchmarks
- Rationalize the existing alarms
- Maintain the improved alarm system

SAFETY INSTRUMENTED SYSTEMS

Safety instrumented systems (SISs) should be completely separate from the normal control system. All elements in the safety loop (measurement devices, logic systems, and actuators) must be highly reliable. This alarm system protects the facility against major catastrophes and will often take corrective actions to safely shutdown and isolate a piece of equipment or a facility, using emergency shutdown (ESD) systems that activate emergency block valves and emergency isolation valves.

The instrumentation settings cannot be changed by the operations personnel. Needless to say, an extremely thorough safety review and Management of Change (MOC) analysis must be performed before these critical alarm values can be changed.

A fully automated SIS should be installed when:

- The facility is unattended.
- Safe plant shutdown involves a critical sequencing of individual unit and equipment shutdowns.
- The operator cannot respond quickly enough to avoid a hazardous situation.
- The operator is presented with too much information to troubleshoot and respond appropriately to plant upset conditions.
- An installation is of high value.

An SIS is composed of a separate and independent combination of sensors, logic solvers, final elements, and support systems that are designed and managed to achieve a specified SIL. An SIS may implement one or more safety instrumented functions (SIFs), which are designed and implemented to address a specific process hazard or hazardous event. The SIS management system should define how an owner/operator intends to assess, design, engineer, verify, install, commission, validate, operate, maintain, and continuously improve their SIS. The essential roles of the various personnel assigned responsibility for the SIS should be defined and procedures developed, as necessary, to support the consistent execution of their responsibilities.

REGULATIONS AND STANDARDS

Two of the key standards to do with safety instrumentation are IEC 61511 and IEC 61508. They are performance-based, nonprescriptive standards that provide a detailed framework and a lifecycle approach for the design, implementation, and management of safety systems applicable to a variety of sectors with different levels of risk definition.

IEC 61511

IEC 61511—Functional safety—SISs for the process industry sector—provides practices in the engineering of systems that ensure the safety of an industrial process through the use of instrumentation. It covers the application of electrical, electronic, and programmable electronic equipment. While IEC 61511 does apply to equipment using pneumatic or hydraulic systems to manipulate final elements, it does not cover the design and implementation of pneumatic or hydraulic logic solvers. The ANSI/ISA 84,001,01-2004 standard is very similar to IEC 61511, which has been adopted in Europe as EN 61511.

IEC 61511 covers the design and management requirements for SISs from cradle to grave. Its scope includes initial concept, design, implementation, operation, and maintenance through to decommissioning. It starts in the earliest phase of a project and continues through startup. It contains sections that cover modifications that come along later, along with maintenance activities and the eventual decommissioning activities.

The standard consists of three parts:

1. Framework, definitions, system, hardware, and software requirements
2. Guidelines in the application of IEC 61511-1
3. Guidance for the determination of the required safety integrity levels (SILs)

IEC 61508

IEC 61508—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems—(which is in multiple parts) focuses on electrical/electronic/programmable safety-related systems. However, it also provides a framework for safety-related systems based on other technologies including mechanical systems. The IEC 61511 is added by the IEC specifically for designers, integrators, and users of SISs and covers the other parts of the safety loop (sensors and final elements) more in detail.

The European standard EN 12186 (formerly the DIN G491) and more specific the EN 14382 (formerly DIN 3381) has been used for the past decades in (mechanically) instrumented overpressure protection systems. These standards prescribe the requirements for the overpressure protection systems, and their components, in gas plants. Not only the response time and accuracy of the loop but also safety factors for oversizing of the actuator of the final element are dictated by these standards. Independent design verification and testing to prove compliance to the EN 14382 standard is mandatory. Therefore, the users often refer to this standard for HIPPS design.

SAFETY INTEGRITY LEVEL

ISA 84.01/IEC 61511 uses an order of magnitude metric, the SIL, to establish the necessary performance. A hazard and risk analysis is used to identify the required safety functions and risk reduction for specified hazardous events. Safety functions allocated to the SIS are SIFs; the allocated risk reduction is related to the SIL. The design and operating basis is developed to ensure that the SIS meets the required SIL. Field data are collected through operational and mechanical integrity program activities to assess actual SIS performance. When the required performance is not met, action should be taken to close the gap, ensuring safe and reliable operation.

The SIL is obtained during the risk analysis of a plant or process and represents the required risk reduction. The SIS shall meet the requirements of the applicable SIL which ranges from 1 to 4. The IEC standards define the requirements for each SIL for the life cycle of the equipment, including design and maintenance. The SIL also defines a required probability of failure on demand (PFD) for the complete loop and architectural constraints for the loop and its different elements.

Design

With regard to the design of critical instrumentation and safety systems the following guidance should be considered:

- Provide critical systems with their own sensors, signal transmitters, and actuators or operating parts, separate from the process control functions.
- Design critical alarms and safety interlock systems to fail to a safe condition on loss of power or instrument air.
- Monitor and alarm critical process variables directly instead of indirectly. For instance, if low flow to a furnace is a concern, monitor the flow directly instead of interpreting other variables such as temperature or pressure that may indicate low flow.
- Manual activating controls (switches, pushbuttons) must be accessible during the fire or release. As a general rule, the controls should be located at least 20 meters from the protected equipment. More spacing may be required depending on the layout of the plant and the type of hydrocarbon being handled.
- Safety interlock systems should have pre-shutdown alarms to warn that a trip is impending. This enables the operator to take corrective action if time permits before the shutdown actually occurs.
- Safety interlock systems should have a manual reset so that the process remains shut down until it is manually cleared by the operator. A manual reset eliminates the potential hazards of the protective system clearing (and the shutdown valve opening) before the condition that caused the shutdown has been investigated and rectified.
- Power supplies and distribution should allow nonsafety-related equipment to be shut down for maintenance without impairing the safety interlock system operation.
- Whenever possible, the safety interlock system should be used to shut down equipment as part of a planned shutdown in order to test the protective system.
- Safety interlock systems should be well labeled and visible.

Quantitative analysis

At the heart of an SIS system is a quantitative analysis. Rather than providing a prescriptive formula regarding the use of safety instruments, a facility determines the quantitative level of risk with the plant in its current configuration and compares that value with the desired value of risk (SIL). If there is a gap, i.e., if the calculated risk is higher than the desired value, then an SIS can be installed. (SIS is not a process safety management requirement under OSHA's standard, although it is certainly recognized as being an excellent voluntary standard and "recognized and generally accepted good engineering practice.")

Table 14.1 Test, Inspection, and Repair Methods for Safety Instruments

Program Element	Program Requirements
Design basis/requirements	ANSI, NEC
Inspection/test procedures	In-line or in-vessel instruments according to piping and valve requirements
Inspection/test frequencies	Operating experience. Minimum of once per annum
Inspection/test acceptance criteria	In-line or in-vessel instruments according to piping and valve requirements
Repair and alteration procedures	Manufacturer's instructions

Testing and inspection

Design of critical systems should allow for in-service testing from the sensor to the final element and in-service maintenance/calibration. The frequency of testing is important. For example, the reliability of a simple level alarm increases by a factor of 15 with monthly testing as opposed to testing on a 3-year turnaround. Testing is even more critical on energize-to-trip systems where a component failure will not cause a shutdown or alarm, *i.e.*, the system is not completely fail safe.

The test procedures should include:

- Testing the alarm and/or shutdown back to the initiating signal. For example, this could mean first verifying the accuracy of the level transmitter, then raising the level to activate the alarm and/or shutdown system.
- Cycling the shutdown valves through their full stroke to the closed position to determine if they have tight shutoff.
- Documenting alarm and/or shutdown set points, test results, date of test, name of person performing the test, instrument number, and type of test performed.

Representative test, inspection, and repair methods for safety instruments are shown in Table 14.1.

EMERGENCY SHUTDOWN

It is vital that the shutdown system be highly reliable. Hence, it will generally be subject to a SIL review and should be developed in accordance with IEC 61508 and analyses, including HAZOPs and review of API RP 14C.

Generally, ESD valves should be provided at all battery limits, on all hydrocarbon product streams to storage. They should have the following attributes:

- Fail Closed (FC)—on failure of air or electrical power
- Supplied with power from the UPS
- Fire safe (valve and actuator)
- Provided with position transmitters and indicators

The above conditions allow a fail-safe system for the ESD valves and positive confirmation that the ESD valves have operated correctly. ESD valves should not be used for process control to maintain the integrity of the ESD system.

In addition to the automatic shutdown of process equipment or units, the plant should be provided with facilities to effect a manual ESD of major process equipment. These should comprise emergency pushbuttons located in the field and appropriate control rooms. They should be specified to be:

- Hardwired to the ESD system.
- Fail safe.
- Protected against inadvertent operation.
- Manually reset.
- Located at grade and at a safe and accessible location.
- Located at a minimum distance of 15 meters away from the equipment (onshore only; for vessels and fired heaters).

Manual shutdown stations should use a two-stage operation to avoid inadvertent operation. For example, a push button could be covered with a flap guard thus requiring that the operator take two actions (open the flap then press the button) before the shutdown takes place.

HIPPS

A High Integrity Pressure Protection System (HIPPS) is a particular type of SIS that prevents overpressure scenarios. It shuts off the source of high pressure before the safe upper limit is reached. It is a barrier between high- and low-pressure sections of a system.

In traditional systems, overpressure is dealt with through a relief system which provides an alternative outlet for the fluids in the system once a set pressure is exceeded, whereas a HIPPS aims at stopping the inflow of excess fluids by containing them within the system.

Conventional relief systems have disadvantages such as release of (flammable and toxic) process fluids or their combustion products in the environment and often a large footprint of the installation. With the increasing environmental awareness, relief systems are not always an acceptable solution. However, because of their simplicity, relatively low cost, and wide availability, conventional relief systems are still often applied. Hence, the justification for a HIPPS is that an overpressure situation can be controlled without the need for venting or flaring, thus avoiding environmental problems.

A HIPPS is a complete functional loop consisting of the following:

- Sensors (or initiators) that detect the high pressure
- A logic solver, which processes the input from the sensors to an output to the final element

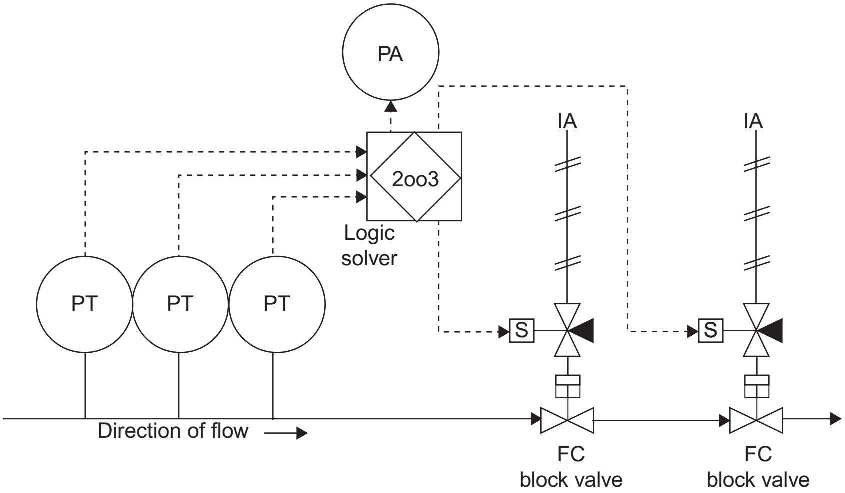

FIGURE 14.1

Example of HIPPS.

- Final elements that perform the corrective actions, typically within 2 seconds, needed to bring the process to a safe state. The final elements consist of the following:
  - One or more valves
  - An actuator
  - Solenoids

The scheme in Figure 14.1 shows three pressure transmitters (PTs) connected to a logic solver. The solver will decide based on 2-out-of-3 voting whether or not to activate the final element. The final elements consist here of two block valves that stop flow to the downstream facilities (right) to prevent them from exceeding a maximum pressure. The operator of the plant is warned through a pressure alarm (PA) that the HIPPS was activated. This system has a high degree of redundancy. Specifically:

- Failure of one of the three PTs will not compromise the HIPPS functionality, as two readings of high pressure are needed for activation.
- Failure of one of the two block valves will not compromise the HIPPS functionality, as the other valve will close on activation of the HIPPS.

CHAPTER

15 Transportation

CHAPTER OUTLINE

INTRODUCTION

Many incidents occur during the transportation of people and freight. This chapter discusses some of the special safety issues to do with this topic. Also discussed here is the control of static electricity when loading and unloading liquids to and from tank trucks and railcars.

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REGULATIONS AND STANDARDS

The transportation business is highly regulated. Some of the standards that apply to process operations are listed below.

STATIC ELECTRICITY

- API RP 2003—Recommended Practice for Protection Against Ignition Arising Out of Static, Lightning, and Stray Currents.
- International Safety Guide for Oil Tankers and Terminals. Ship to Shore Electric Currents.

OFFSHORE

- API RP 2D—Operation and Maintenance of Offshore Cranes, Sixth Edition (2007)
- International Marine Contractors Association. Transfer of Personnel to and from Offshore Vessels
- CAP 437—Offshore Helicopter Landing Areas
- API RP 2L—Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms, Fourth Edition
- OSHA 1926.551—Helicopters, Hoists, Elevators, and Conveyors (2010)

TRUCKS

- API RP 2219—Safe Operation of Vacuum Trucks in Petroleum Service, Third Edition (November 2005)

ROAD VEHICLES

Process chemicals and hydrocarbon fuels of all kinds are transported by road. These vehicles are generally referred as tank trucks, and distinct from tank cars, which travel by rail. Issues to do with the loading and unloading of tank trucks are discussed in this section. The same general principles apply also when loading or unloading tank cars, barges, or ships.

VACUUM TRUCKS

Vacuum trucks are widely used in refineries and chemical plants to recover hazardous materials that cannot be completely purged or drained prior to maintenance or project work. They can also remove materials from open ditches and from tanks and vessels. The trucks carry the materials to a disposal site.

("Vac-All" trucks are not vacuum trucks. They convey solid material with a high-velocity air stream. Trucks of this type should not be used for liquid hydrocarbons or flammable liquids because the high velocity of the air can create ignitable mists and sprays.)

The vacuum needed to pull liquids into the truck is generally created by a vacuum pump on the truck itself. The action of the pump is reversed when the tank's contents are to be pumped out (although gravity flow is preferred). The pump is driven either by the truck's engine or by an auxiliary power unit.

Hazards associated with vacuum truck operation include the following:

- The vacuum truck can serve as an ignition source
- The truck could discharge hazardous vapors or gases in the explosive range
- The flash points for some liquids are lower under vacuum—some materials may flash at ambient temperatures
- The release of hydrogen sulfide from sour liquids under vacuum

Due to turbulence and high velocity in the liquid being pumped, static charges are frequently generated during vacuum truck operations. To prevent charges from accumulating on an insulated section of hose, it is important to check the continuity of the hoses and to ensure all hoses are conductive from the truck to the equipment. This prevents a spark gap between the hose nozzle and the equipment.

The following guidelines apply to vacuum truck operations.

- The truck operator should be informed of the hazards of the material being picked up and required to use the appropriate personnel protective equipment.
- Gas tests for flammables or toxics should be made where appropriate and necessary work permits issued, before allowing a vacuum truck to enter the affected area and during operation.
- Vacuum trucks should be operated upwind and outside of gaseous areas.
- If the receiving tank is not empty, the material being picked up should be compatible with any material present in the tank, as well as the material of construction of the tank, hoses, and pump.
- Light hydrocarbon liquids may vaporize when placed under vacuum, resulting in significant turbulence inside the receiving tank and large quantities of hydrocarbon gas venting from the vacuum truck exhaust hose. Vacuum trucks should not be used to pick up liquids with a vapor pressure above about 0.7 bars absolute at ambient temperature.
- The vacuum truck pump exhaust should be discharged downwind of the vehicle by attaching a length of hose to permit venting to an area free from a source of ignition and to insure it does not present a hazard to personnel. Periodically confirm that personnel in adjacent areas are not affected by this exhaust.
- The truck should be equipped with a low resistance ground wire to ground the vacuum truck and hoses at all times during loading and unloading.

- The vacuum truck suction hose should be conductive throughout; if not, any exposed metal such as a hose flange should be grounded or bonded.
- Collection funnels used to guide flowing liquid into a pan should extend to the bottom of the pan to help prevent electrostatic discharge.
- Vacuum trucks should preferably be unloaded by gravity flow. When the truck mounted pump is used to unload the tank, the end of the discharge hose should be located a safe distance from the engine.

ALL-TERRAIN VEHICLES

All-terrain vehicles (ATVs) are particularly hazardous because they operate away from paved surfaces, often on hilly terrain, and so they are liable to roll over. The following guidance should be followed when using ATVs:

- They must be fitted with seatbelts and rollcages.
- Only one person is permitted on an ATV during operation.
- Operation should be only during daylight hours.
- The following personal protective equipment (PPE) should be used:
  - ANSI-approved helmet
  - Face shield or goggles
  - Leather gloves
  - Long sleeve shirt (or jacket) and pants
  - Leather work shoes
- They should be driven off-road only, never on public roads.
- Drivers should perform a walk around inspection daily or before each use.
- All employees must attend ATV safety training prior to operating an ATV and periodically thereafter.

LOADING/UNLOADING

When a tank car that transports liquids is loaded or unloaded a charge is generated in the fill pipe and container, and an opposite charge is generated in the liquid. These static charges have the potential to create a spark that could ignite the vapors in the space above the liquid or around the loading hatch. The spark could cause a fire if the vapor/air mix is in the flammable range, and if the ambient temperature is above the material's flash point. Therefore, in general, when handling volatile liquids, it is important to maintain an electrical path between the pipe and container in order for these charges to recombine without the chance of producing a spark, particularly for refined products which tend to have a low conductivity (other materials such as crude oil and water-soluble materials have a higher conductivity).

Sparks can be produced in the following situations:

- Between the loading spout and the vehicle
- Between the surface of the oil in a compartment of the vehicle and the wall or structural component of that vehicle
- Between an unbonded conductive object in the compartment and the compartment structure
- Between a gauging device or sample container and the liquid surface

GENERAL PROCEDURES

The following guidance can be considered when loading and unloading trucks or tank cars and when control measures are required. (The topic of Loading Racks is discussed in Chapters 1 and 11.)

- For top loading, a bond wire between the fill pipe and the vehicle is required before opening the dome cover.
- The dome cover should be closed before the bond wire is removed.
- The compartments of tank trucks must be carefully inspected to verify that they are free of any loose conductive material such as fittings prior to loading.
- The fill pipe should be in contact with the bottom and fitted with a suitable splash deflector.
- For bottom loading, use low velocity or splash deflectors to prevent upward spraying and to minimize surface turbulence. Limit liquid velocity in the fill line to approximately 1 m/s until compartment inlet is submerged to a depth of at least two inlet diameters.
- Limit liquid velocity in fill pipe to approximately 1 m/s until the outlet is submerged.
- Provide 30 seconds minimum residence time downstream of filters or wire screens with a pore size smaller than 150 microns (more than 100 mesh per inch).
- Any filters in the line can greatly increase the static charge on the liquid. They may require that a minimum pipe residence time at a suitably low flow velocity is provided.
- The loading arm should be extended down to the bottom of the tank so as to avoid splashing.
- Liquid velocities should be kept below 1 m/s until the bottom of the fill spout is covered with liquid and there is no splashing. The velocity can be increased after the fill spout is covered.
- The limit loading velocity in the fill pipe and immediately upstream of the fill pipe should be <7 m/s or calculated from an approved formula. (Table 15.1 provides an example for Schedule 40 pipe.)
- After loading or emptying is complete, there should be a pause of at least 1 minute before gauging or sampling is carried out.

Table 15.1 Guidance for Maximum Velocities and Flow Rates in Schedule 40 Pipe

	Flow Velocity (m/s)	Flow Rate (l/s)
1.5	7.00	9.19
2	7.00	15.1
3	7.00	33.3
4	7.00	57.5
5	6.24	80.4
6	5.18	96.5
8	3.95	127
10	3.14	159
12	2.64	191

Further guidance to do with loading and unloading trucks is provided in API RP 2003.

CONTROL MEASURES

The need for control measures such as bonding and the use of additives depends on various factors, including the following:

- The flash point of the liquid (this term is defined in Chapter 1)—in particular whether it is below ambient temperature
- The vapor pressure of the liquid
- The conductivity of the liquid
- The ambient temperature

In general, control measures are required if the material being loaded or unloaded is above its flash point and has a vapor pressure such that flammable mixtures can be formed in the tank car or in the area adjacent to the loading/unloading point. For example, toluene is an intermediate vapor pressure material that is flammable at most commonly occurring loading temperatures and is also a prolific generator and accumulator of static electricity. Methanol is also flammable over a wide range of likely loading temperatures, but it is not a static accumulator. Hence, toluene requires extensive precautions whereas methanol generally requires no static control measures.

Stringent control measures may not be required in the following circumstance. However, it is critical that each situation be analyzed and the appropriate procedures and safeguards be put in place.

- If the liquid (gasoline is an example) has a high vapor pressure. This will make the vapor space in the tank car "fuel rich." However, the vapor around the open hatch may be in the flammable range.

- If the liquid has a low vapor pressure such that the vapor space in the tank car will be "too lean." Once more, though, the area around the hatch may be in the flammable range.
- If the product being loaded is not a static accumulator. Examples include residual oils, asphalts, most crude oils, water-soluble products such as ethanol, and any product that has been treated with a sufficient quantity of antistatic additive.
- When the products have a flash point above 40°C and no significant amounts of mist or aerosol are formed during the loading operation.

BONDING

Bonding is an important static control measure. A wire connects the two parts of the loading/unloading process thus ensuring that no static potential builds up between them. When top loading high vapor pressure, low flash point products such as gasoline through open hatches, bonding the loading spout to the tank truck (and avoiding splash loading and spraying) will normally suffice to prevent static-spark ignition. (At normal loading temperatures, these products will produce a "too-rich" mixture to be flammable inside a tank-truck compartment. However, a flammable concentration may exist near the loading spout and hatch.)

Even when bonding for bottom loading through closed connections is not strictly required on technical grounds it may still be required by code.

SWITCH LOADING

Switch loading occurs when a tank truck carries a low flash point material such as gasoline and then carries a liquid (such as heating oil) with a higher flash point without first purging the vapor space. This practice can create static ignition hazards because the heavier material can absorb some of the vapor left behind from the low flash product. Hence, the vapor space may no longer be "fuel rich" and an explosive mixture may form.

TANK/RAILCARS

In general, the causes and mitigating actions associated with static hazards in tank cars are the same as those associated with tank-truck loading. There are a few differences, however.

- Because tank cars are larger than tank trucks electric-field intensities associated with a given electric charge density in the incoming fluid are less. Hence, charge densities loading velocities can in some cases be larger than those allowed in tank-truck loading.
- Tank car loading facilities lends itself to the installation of permanently installed bond wires between the loading line and the tank car via the rails.

An installed bond system can provide both stray-current and static-electricity protection at these facilities. In some cases, insulating flanges may have been installed in the loading line to provide stray-current protection. Where this is the case, the bond connection should be located downstream of the insulating flange.

- If a permanent bond wire is not installed, the tank car must be properly grounded by either attaching a bond wire between the fill pipe and the tank, or attaching a bond wire between the tank and its chassis.
- Some tank cars are fitted with thick plastic plates on which the tank itself rests. This means that electrical continuity between the tank and its chassis may be compromised unless such a tank car is equipped with a bond wire between the tank and its chassis. The existence of these plates and the integrity of an installed bond wire may not be readily detectable by casual inspection.

ADDITIVES

In addition to standard procedures that are always to be taken when unloading cars or trucks antistatic additives can also be used. These additives increase the conductivity of the distillate products, thus allowing static charges to dissipate quickly. The additives can be blended either into the product tanks or into the product loading lines.

MARINE TRANSPORT

Boats are used offshore for a wide variety of purposes including the transfer of supplies, the movement of personnel, and the export of oil and other liquid products. Boats may also be used in specialized situations such as accessing pumps in firewater ponds. The following general guidance should be considered:

- Boats must be registered as required and have appropriate numbers displayed.
- The boat must be tied off immediately upon arrival at the work area.
- Personnel on board the boat should always wear standard PPE, including safety glasses, a hard hat and approved shoes or boots.
- Whenever possible, work activities should be scheduled in the daylight hours. If the boat must be used during at night navigation lights should be installed and in proper working order.
- The weight of personnel and equipment in the boat should not exceed the maximum load for the boat.
- The following minimum equipment must be supplied on all boats:
  - Coast Guard-approved Life Jacket (Type I, II, III, or V) to be worn by each person during boarding and while the boat is in operation
  - Coast Guard-approved Life Rings and Visual Distress Signals

    - Paddles (two or more)
    - Tie-off rope
    - Coast Guard-approved Life Ring (Type IV) with rope
    - Flashlight
    - A Type B-1 Fire Extinguisher
    - Communication devices should be provided for emergency use, including a whistle or horn
    - First aid kit
- If provided, seatbelts should be worn.
- Loose items that may fall overboard due to wind or water chop must be secured.

The fueling of boats can be particularly hazardous. The following guidance should be considered:

- Refuel portable tanks off of the vessel.
- Close all hatches and openings before fueling.
- If smoking is permitted, extinguish all smoking materials.
- Turn off engines, electrical equipment, and other appliances that could create a spark.
- Remove all passengers.
- Keep the fill nozzle in contact with the tank.
- After refueling:
    - Open all ports, hatches and doors to ventilate
    - Check the bilge for fuel vapors before starting the engine
    - If there is a smell of fuel vapor do not start the engine
    - Let the blowers run for at least 4 minutes before starting the engine

PERSONNEL TRANSFER BASKETS

Personnel baskets (sometimes called Billy Pugh baskets) are used to transfer personnel from platforms and rigs to and from service boats. The basket (illustrated in Figure 15.1) consists of ropes attached to a hook at the top and a circular frame at the bottom. Personnel stand on the outside of the basket looking inwards.

The personnel transfer basket also serves as a temporary life raft for its maximum capacity—typically four passengers. It should also be equipped with a tag line and have a shock-absorbing suspension that cushions impact when the basket is lowered to the moving deck of a boat.

Use of the transfer basket looks dangerous. A person is swinging over the ocean or platform machinery and could fall to their death just by letting go. Yet in a YouTube video Liberato states

> *The irony is that statistically, you are MUCH more likely to die in a helicopter transfer than a personnel net transfer.*

FIGURE 15.1

Personnel Transfer Basket 1.

Nevertheless, in order to improve safety some companies are using rigid frame baskets, with the personnel being inside the frame, rather like a cage. Although this approach does reduce the risk of falling, it does raise the concern that the personnel inside the frame might not be able to escape if the basket goes underwater.

The following guidance is provided for use of personnel transfer baskets:

- Use a netted baggage area or cargo basket for personal belongings. Personal belongings such as computers, tools, and papers should not be put on the floor of the personnel basket because, if the load falls off, the person riding the basket will not be tempted to reach out and grab it.
- Persons being transferred should be in good health—in particular, they should not be suffering from sea sickness.
- All personnel must wear an approved personal floatation device (PFD).
- The quick release safety lanyard clip should be attached to the upper nylon strap of the Work Vest between the stitching, not onto the PFD fastener. (The safety lanyard serves as a fall restraint and should not be considered fall protection.)
- There must be a clear space at both the departing and arrive decks.
- A deck hand must be on the deck of the boat during all personnel transfers to assist with safe placement and landing of the basket. He or she will coordinate lifting activities with the crane operator.

- The master of the vessel, the crane operator, and the deck crew should be in radio communication the whole time.
- Only the persons assisting the transfer and personnel to be transferred on the personnel basket are to be in the pickup or set-down area.
- Crane hooks used to lift personnel baskets will have a positive locking device equipped with a locking pin. Spring-loaded latches and self-latching mechanisms must also be closed and secured with a locking pin.
- All shackles incorporated in a personnel basket-lifting configuration will be tight and wire locked.
- The crane operator, while transferring personnel between vessels or from a vessel to a platform, should raise the personnel basket only high enough off the deck to clear all obstructions.
- Personnel lifts to and from a motor vessel shall be swung over water and not directly over the vessel whenever possible.
- The number of personnel and/or weight allowed to ride on the personnel basket shall not exceed the manufacturer's rated capacity.
- Tag lines should be free of knots and must be a minimum of 3 meters in length.
- Personnel transfer baskets should not be used to raise or lower personnel into or out of tanks or other production vessels.
- All personnel lifts shall be under power control both up and down.
- Swing ropes are not allowed.

When boarding the basket, the following guidance should be considered:

- Pass arms around the inner rigging ropes, cross them for more grip, and keep the quick release clip strap in one hand.
- Place one foot firmly on the rim of the floor of the basket, keep the other foot on the deck (this will prevent collapse if the crane operator takes tension off the lifting cable prematurely).
- Place feet on the painted footprints on the basket floor (if provided).
- Attach the safety lanyard.
- Once the basket lifts off the deck, place both feet firmly on the basket perimeter.
- During the transfer, stand on the outer rim of the net facing inward. Insert arms through the ropes, then cross hands so that the arms interlock.
- Bend knees slightly to absorb any sudden movement or jarring of the basket.

The following guidance is provided for leaving the basket:

- As the basket descends on to the receiving deck keep the knees bent in case the crane operator drops the basket suddenly.
- Step off the basket once tension is off the crane cable.
- If the transfer is to a smaller boat do not step out of the basket at the top of the swell because the boat may fall away.

CARGO BASKETS

Cargo baskets are used to transfer equipment and supplies between service boats and offshore facilities. Guidance is provided in *Design and Handling of Cargo Baskets* published by the Step Change in Safety organization, the Table of Contents for which is shown in Table 15.2.

Table 15.2 Cargo Baskets

1. General
   - 1.1 Scope
   - 1.2 Definitions
2. Standard Dimensions
   - 2.1 Lengths
   - 2.2 Widths
   - 2.3 Heights
3. Design of Fork Pockets
   - 3.1 Fork Pocket Spacing
   - 3.2 Fork Pocket Welding
4. Padeyes
5. Inspection and Loading
   - 5.1 Cargo Basket Selection
   - 5.2 Inspection of Cargo Baskets Before Loading
   - 5.3 Loading the Cargo Basket
6. Snagging Hazards
   - 6.1 Snagging Hazards Inside the Basket
   - 6.2 Snagging Hazards Outside the Basket
7. Eliminating Dropped Objects
   - 7.1 Design of Floor
   - 7.2 Design of Sides
   - 7.3 Design of Base
8. Stacking Arrangements
   - 8.1 Stacking Mechanisms
   - 8.2 Stacking Compatibility Markings
9. Cargo Securing Methods (Restraining Contents)
   - 9.1 Tie Down Points
   - 9.2 Cargo Securing Mechanisms
10. Safety Markings
    - 10.1 Basket Top
    - 10.2 Basket Ends
    - 10.3 Stacking Information
11. Tag Lines
12. Basket Selection
    - 12.1 Component/Design Engineer
    - 12.2 Cargo Basket Selection (Planning, Loading, and Logistics)

(*Continued*)

Table 15.2 Cargo Baskets *(Continued)*

	12.3 Securing of Components into Cargo Baskets
	12.4 Transportation, Loading, and Forwarding
	12.5 Loading and Lifting Operations
13.	Horizontal Lifts (Balance of Loads)
14.	Transport
	14.1 Securing of Cargo
	14.2 Vehicle Loading
15.	Load Security Inspection Procedure
	15.1 Load Security Inspection Procedure
	15.2 Load Security Inspection Procedure—Flowchart
16.	Offloading and Backloading Operations
	16.1 Onshore Yards
	16.2 Quayside/Offshore Loading or Offloading to or from Supply Vessels
	16.3 General Workings of Supply Vessels
	16.4 Unloading Cargo Baskets Onshore/Offshore
17.	Stacking Offshore
	17.1 Additional Deck Cargo Basket Stacking Provisions
18.	References

Rigid frame baskets

Modern designs of transfer baskets provide a rigid structure and do not allow personnel to fall off them. There are two types commercially available. One is the Esvagt, which has a rigid frame construction with buoyancy ring and fenders. Personnel stand inside the basket. Another design is the Personnel Transfer Capsule: a rigid frame device with buoyancy panels. Personnel sit strapped into bucket seats.

HELICOPTERS

Helicopters are used to transport personnel and light freight to and from offshore platforms. They are also used for the emergency evacuation of injured personnel (but cannot be used if the platform or rig is sinking or on fire). The crash of a helicopter is almost always a very serious event—often leading to fatalities and serious economic loss.

GUIDANCE

The following general guidance to do with the operation of helicopters offshore is provided.

Personnel movement

Personnel boarding a helicopter must wait in a designated area before going on to the helideck itself. And they must then follow crew directions as to where to go. Similarly, personnel disembarking from the helicopter should always follow the instructions of the deck crew.

Personnel using helicopters should understand the following:

- The authority of the pilot
- How to communicate with the pilot
- Whenever approaching or leaving a helicopter with blades rotating, all employees shall remain in full view of the pilot and keep in a crouched position
- Employees shall avoid the area from the cockpit or cabin rearward unless authorized by the helicopter operator to work there
- There shall be constant reliable communication between the pilot, and a designated employee of the ground crew who acts as a signalman during the period of loading and unloading. This signalman shall be distinctly recognizable from other ground personnel
- No unauthorized person shall be allowed to approach within 15 meters of the helicopter when the rotor blades are turning
- Manifest rules and weight limitations on personal effects
- Handling of light objects that could be blown away by rotors
- Use of lifejackets, seating arrangements, seatbelts, and the storing of cargo
- Safe conduct during flight
- Emergency procedures.

Air turbulence

A particular concern to do with helicopter operations associated with offshore oil and gas production is air turbulence—particularly the turbulence that comes from the generator turbines.

Rescue

Helicopters can be used to remove injured personnel from an offshore facility. However, if there is an onboard fire—or there is the potential for such a fire—helicopters should not approach the facility.

REGULATIONS AND STANDARDS

The U.K. Civil Aviation Authority provides guidance for the safe operation of helicopters in its CAP 437—Standards for Offshore Helicopter Landing Areas. The Table of Contents for this standard is shown in Table 15.3 (it has been lightly edited to save space).

Table 15.3 Contents for CAP 437

Chapter 1: Introduction
History of Development of Criteria for Offshore Helicopter Landing Areas
Department of Energy and the Health and Safety Executive
Guidance on the Design and Construction of Offshore Installations, 1973 Onwards
Applicability of Standards in Other Cases
Worldwide Application
Chapter 2: Helicopter Performance Considerations
General Considerations
Safety Philosophy
Factors Affecting Performance Capability
Chapter 3: Helicopter Landing Areas—Physical Characteristics
General
Helideck Design Considerations—Environmental Effects
Structural Design
Loads—Helicopters Landing
Loads—Helicopters at Rest
Size and Obstacle Protected Surfaces
Surface
Helicopter Tie Down Points
Safety Net
Access Points
Winching Operations
Normally Unattended Installations
Chapter 4: Visual Aids
General
Helideck Landing Area Markings
Lighting
Obstacles—Marking and Lighting
Chapter 5: Helideck Rescue and Firefighting Facilities
Introduction
Key Design Characteristics—Principal Agent
Use and Maintenance of Foam Equipment
Complementary Media
Normally Unattended Installations
The Management of Extinguishing Media Stocks
Rescue Equipment
Personnel Levels
Personal Protective Equipment (PPE)
Training
Emergency Procedures
Further Advice

Table 15.3 Contents for CAP 437 *(Continued)*

Chapter 6: Helicopter Landing Areas
Landing Area Height Above Water Level
Wind Direction (Vessels)
Helideck Movement
Meteorological Information
Location in Respect to Other Landing Areas in the Vicinity
Control of Crane Movement in the Vicinity of Landing Areas
General Precautions
Installation/Vessel Helideck Operations
Helicopter Operations Support Equipment
Chapter 7: Helicopter Fueling Facilities
General
Product Identification
Fuelling System Description
Chapter 8: Helicopter Fueling Facilities
General
Fuel Quality Sampling and Sample Retention
Recommended Maintenance Schedules
Filling of Transit Tanks
Receipt of Transit Tanks Offshore
Decanting from Transit Tanks to Static Storage
Fueling Direct from Transit Tanks
Long-Term Storage of Aviation Fuel
Aircraft Refueling
Quality Control Documentation
Chapter 9: Helicopter Landing Areas on Vessels
Vessels Supporting Offshore Mineral Workings and Specific Standards for Landing Areas on Merchant Vessels
Amidships Helicopter Landing Areas—Purpose-Built or Non-Purpose-Built Ship's Centreline
Helicopter Landing Area Marking and Lighting
Ship's Side Non-Purpose Built Landing Area
Ship's Side Non-Purpose Built Landing Area Markings
Night Operations
Poop Deck Operations
Chapter 10: Helicopter Winching Areas on Vessels and Wind Turbine Platforms
Winching Areas on Ships
Helicopter Winching Areas on Wind Turbine Platforms

Further guidance is provided in API RP 2L—Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms, and in OSHA's 1926.551—Helicopters, Hoists, Elevators, and Conveyors.

CHAPTER

16 Security

CHAPTER OUTLINE

INTRODUCTION

On September 25, 2001, just days after the 9/11 attacks, the *New York Times* columnist Thomas Friedman wrote

> *The World Trade Center is not the place where our intelligence agencies failed. It is the place where our imaginations failed.*

Plant Design and Operations. DOI: http://dx.doi.org/10.1016/B978-0-323-29964-0.00016-0

Prior to that attack no one had even conceived that terrorists could take over airplanes and use them to hit large buildings. Now we know.

At about the same time as Mr. Friedman made the above remark, the author of this book was putting the final touches to his book *Process Hazards Analysis* (the contents of which are now incorporated into *Process Risk and Reliability Management*), a basic premise which is that everyone wants process plants to be safe. Although the book was going to the printers at the time of the attacks, there was time to add the following words to the Preface on September 20, 2001.

> *All that I have written here is predicated on the assumption that everyone involved in the design and operation of process plants is of goodwill; that accidents indeed are accidents. Clearly this assumption will have to be revisited.*

Most of the people who work at process facilities have great difficulty comprehending the mind-set of someone who deliberately and willfully wishes to cause massive death and destruction. An implicit assumption behind a process hazards analysis (PHA), e.g., is that, "Everyone wants to do a safe job—accidents truly are accidents—therefore this PHA will exclude malicious acts." Unfortunately, this mental paradigm of "general goodwill" does not always hold.

Normal safety programs and activities such as the use of operating procedures, inspection of equipment, hazards analyses, and the implementation of multiple layers of protection make a catastrophic event, such as a large tank rupture, extremely unlikely to happen. Yet, if a terrorist or even local teenager was to fire a high-powered projectile at a storage tank at a local chemical plant, all of the above safeguards would be for naught: a large and uncontrollable release of hazardous chemicals would ensue immediately.

In addition to the hazards associated with a direct release of chemicals, process facilities may also be concerned with the theft of chemicals that can be used to manufacture weapons of mass destruction, or that could be used to contaminate the environment, particularly the public water supply.

Facilities that handle toxic chemicals are probably more at risk than say an oil refinery. A fire at a refinery may be dangerous for the people who work there but is not likely to have a major impact on the local community. Also, people understand that fires occur on refineries, and that a fire is something that can be contained and controlled. However, if a "mysterious" toxic chemical is released from a chemical plant the fear factor can be very high because no one knows what to expect or what to do.

In one sense, security management can be treated like any other type of risk analysis. Each security threat is a hazard which has consequences and likelihoods, and that calls for the installation of safeguards and the development of emergency response plans. However, there are differences between normal risk analysis and security work. In particular, security analysis requires that everyone at a process facility be imaginative and to "think the unthinkable."

REGULATIONS AND STANDARDS

Various regulations to do with the security of process plants and water treatment facilities have been introduced since the 9/11 attacks. In the United States, Section 550 of the Homeland Security Appropriations Act of 2007 provided the Department of Homeland Security (DHS) with authority to promulgate "interim final regulations" for the security of certain high-risk chemical facilities in the United States. The Chemical Facility Anti-Terrorism Standards (CFATS) regulation (6 CFR Part 27) is risk based and performance based, which makes it both particularly progressive and flexible and yet challenging due to the nature of the rule (Moore, 2008). The United States Environmental Protection Agency (U.S. EPA) has also developed rules and guidance in response to the Public Health Security and Bioterrorism Preparedness and Response Act of 2002. The American Institute for Chemical Engineers Center for Chemical Process Safety (CCPS) has developed a methodology for evaluating the security of chemical plants, as has the Sandia National Labs (VAM-CF or Vulnerability Assessment Methodology for Chemical Facilities). The VAM-CF method takes advantage of existing Process Hazards Analyses (PHAs). Ragan et al. (2002) provide an example of a "Risk Sheet" used to evaluate the security risk associated with a hazardous chemical.

In addition to the hazards associated with a direct release of chemicals, facilities may also be concerned with the theft of chemicals that can be used to manufacture weapons of mass destruction, or that could be used to contaminate the environment, particularly the public water supply.

TYPES OF ATTACK

Malicious attacks can be divided into the following categories:

- By members of the Public
  - Vandalism
  - Theft
  - Activists
- Sabotage
- Terrorism

MEMBERS OF THE PUBLIC

Probably, the most common types of security breach are those caused by members of the public. Although these events have the potential to be serious, they are usually relatively minor because the persons involved do not really know what they are doing or what they are attacking. Moreover, although they may wish to cause damage, they do not usually want to create a catastrophe.

Three types of attacker are considered in this category: vandals, thieves, and activists.

Vandalism

Attacks on process facilities from vandals living in the local community do occur but they are generally not a major threat. In one case, local youths fired B-B guns over the fence of an oil refinery. No serious damage ensued, although some of the pellets did come close to hitting the refinery's critical electrical transformers. A more serious example of the consequences of vandalism is provided by the U.S. EPA. Trespassing teenagers ignited naphthalene at a plant site leading to losses of $100 million.

Another incident occurred on October 9, 2001, when an allegedly drunken hunter used a high-powered rifle to punch a hole in the Trans-Alaska pipeline causing a jet of oil to create a significant environmental impact.

Angry customers can be a threat, not so much to the physical plant as to those who are working in the front office.

Basic security measures, such as having good fences around the facility and the use of routine patrols, can do a lot to deter vandalism.

Theft

Thieves sometimes steal fuels and chemicals for their own use. For example, people have drilled holes in fuel (gasoline or diesel) pipelines in order to steal the contents for their personal use. Not only are such acts dangerous, particularly if the stolen material ignites or spills, but the associated on-going spill can create environmental problems. Thieves also steal ammonia for use in the manufacture of illegal drugs.

As with vandalism, this type of theft can be deterred using basic security measures, although cross-country pipelines are difficult to defend since they are almost entirely in public areas.

Activists

Occasionally, environmental activists will blockade a plant or pipeline in order to protest a policy or activity of which they disapprove. In doing so, they may put both their own lives and the lives of plant workers at risk. They may also, ironically, cause a major environmental release to occur.

Protestors outside the facility, including strike pickets, are generally not likely to cause serious problems to the facility, if only because there are probably a plenty of security personnel (and possibly police) keeping an eye on the situation.

SABOTAGE

If a knowledgeable operator or maintenance mechanic decides to carry out an act of sabotage, he or she can create a very threatening situation. On one chemical plant, e.g., the workers went on strike. As they left the control room they switched many of the control valve loops into a reverse acting mode, so if a control valve needed to be closed it was actually opened. Needless to say the managers, supervisors, and engineers who stepped in to keep the facility running after the workers had walked out found that their first 30 minutes on the job was more than a little interesting.

Probably, the most extreme of sabotage was the Bhopal event. Although there is disagreement as to whether this event was deliberately caused or whether it was an accident, the connection of the water hose to the storage tank strongly indicates malicious intent. Thousands died.

There is little that management can do to defend against knowledgeable personnel who have malicious intent. Modern safety instrumented systems are increasingly difficult to defeat, and any anomalies in settings or performance may quickly be relayed to a central control center. Still, the only truly effective way of preventing against sabotage is to create a positive culture and to identify and remove unreliable employees.

TERRORISM

Terrorism is probably the form of attack that people fear the most, not least because terrorists intentionally want to create such fear. Moreover, terrorists often have much greater destructive capability than other malicious persons, thus giving them the potential to cause a lot of damage and to operate at long range.

Terrorists have a long reach. For example, if they decide to attack a process plant using military-style weapon they could attack from a mile away—thus obviating the effect of normal security fencing and patrols (which are designed to stop trespassers and less sophisticated attackers). Even more crudely, terrorists could simply break through normal security barriers using a heavy vehicle and then plant that vehicle and its contents anywhere within the facility.

The following factors affect the likelihood of a terrorist attack on a process facility.

Visible security

Facilities that have clearly visible security that is present 24 hours a day are probably less likely to be attacked. Items such as floodlighting, strong fencing, and plenty of warning signs all serve to deter a would-be attacker.

Population density

An attack that takes place in an area of high population density is likely to have greater impact than one that takes place in a relatively remote area. Not only will more people be directly affected but the potential for panic is greater. Also, it is more likely that news reporters will be on the scene very quickly than they would be in a remote location.

High profile

The 9/11 attacks were directed at very well-known buildings. In this regard, the process industries are fortunate. It is hard to think of a chemical plant or refinery that could be described as "famous." Indeed, the lack of reporting within the United States on the purported "terrorist attack" on the Toulouse chemical plant that occurred just after 9/11 demonstrated just how "out of sight, out of mind" process plants can be.

Those companies whose names are well known to the public may elect to remove their names and logos from the site perimeter in order to minimize their profile.

SECURITY VULNERABILITY ANALYSES

Many companies conduct a Security Vulnerability Analysis (SVA) in order to identify areas where they may be the most vulnerable, and to decide on how to improve security. An SVA is similar in many ways to a PHA.

An SVA can be divided into the following six sections:

1. Evaluation of on-site hazards
2. Identification of potential adversaries and attackers
3. Assessment of the damage that could be caused
4. Assessment of existing safeguards and protective systems
5. Development of recommendations for improvement
6. Upgrade of the emergency response plan

Any type of risk analysis will be concerned with high consequence events as distinct from risk because likelihood need not be evaluated. It can be assumed that the malicious persons do intend to carry out their attack.

RINGS OF PROTECTION

Security tends to emphasize "rings of protection," meaning that, if possible, the most important or most vulnerable assets should be placed in the center of concentric levels of increasingly stringent security measures. For example, where feasible, a chemical facility's control room should not be placed right next to the building's reception area; rather, it should be located deeper within the site so that, to reach the control room, an intruder would have to penetrate numerous rings of protection, such as a fence at the property line; a locked exterior door; an alert receptionist; an elevator with key-controlled floor buttons; and a locked door to the control room.

The American Chemistry Council (ACC, 2001) states

Security tends to emphasize "rings of protection," meaning that, if possible, the most important or most vulnerable assets should be placed in the center of *concentric levels of increasingly stringent security measures. For example, where feasible, a chemical facility's electronic control room should not be placed right next to the building's reception area; rather, it should be located deeper within the building so that, to reach the control room, an intruder would have to penetrate numerous rings of protection, such as a fence at the property line, a locked exterior door, an alert receptionist, an elevator with key controlled floor buttons, and a locked door to the control room.*

To determine if the rings of protection are effective, security programs are generally evaluated through use of penetration tests in which the facility people play the role of an attacker to see if the barriers work as expected.

CYBERSECURITY

Increasingly companies are investing in cyber security, *i.e.,* protecting their computerized control systems. The protection of critical pipeline assets is discussed by Gylstorff (2012).

MANAGING SECURITY

Having identified security issues, the next step is to come up with a program to address those issues. Detailed guidance is provided in the American Chemistry Council's *Site Security Guidelines* already referred to. A critical component of the security plan is to develop a good working relationship with the appropriate law enforcement and emergency response agencies.

CULTURE

Simmons and Robb (2007) stress the importance of having an alert and aware work force. They quote a number of cases where facilities that possessed strong technical security measures were nevertheless successfully attacked because employees were not sufficiently alert and risk aware. In other words, security is part of the development of an effective culture.

A simple example shows how safety culture could have been improved. A consultant was calling on a client at a chemical plant that manufactures large quantities of very hazardous chemicals. The consultant and his client knew one another very well. The consultant registered with the security guard at the front gate. The security guard called through to the client who gave them permission to allow the consultant to drive his personal automobile on to the plant site. If the client had been "thinking security," he would have asked the security person to put the consultant on the phone. That way the client would have been able to identify his voice and confirm his identity.

INHERENT SAFETY

As with all types of risk reduction program, where possible hazardous chemicals should be replaced with other materials that are inherently less dangerous, inventories should be kept to a minimum and storage tanks should be kept apart from one another and from the processing units. Then, if there is a breach of security, the worst case scenario is not as bad as it might have been.

ACCESS SECURITY

The term "access security" generally refers to physical or behavioral measures for managing the passage of personnel and vehicles into, out of, and within a facility. An access control plan strives to exert enough control to protect the facility while still allowing employees and contractors enough freedom of movement to work effectively. Access security involves the appropriate use of physical devices such as fences, perimeter lights, and closed circuit TV.

PERSONNEL SCREENING

Personnel screening can be used to ensure that new employees, contract workers, and even visitors do not have a record that suggests that they might pose a threat. Screening will, of course, do nothing against vandals, thieves, or terrorists—all of whom are anonymous before the event.

EQUIPMENT MODIFICATIONS

As has already been stressed, some of the systems such as safety instrumented systems that are installed to handle "normal" risk may not be as effective in response to a malicious attack. However, other devices such as excess flow valves (see Chapter 13) could be particularly helpful, regardless of the source of the event.

Do not inform other personnel of the threat. Management is responsible for notifying authorities and initiating an emergency response and/or building search may result.

RESPONSE TO A THREATENING CALL

If someone calls in with a threatening message, it suggested that the general rules shown in Table 16.1 should be followed. This example is specifically to do with a bomb threat, but can be used for other types of threat. Table 16.2 provides a questionnaire that can be completed by the person taking the call.

Table 16.1 Outside Call Checklist— Part 1

- Be calm, courteous, and listen carefully
- Get as much information as possible from the caller, but avoid the impression you are working from a checklist (even though you are)
- Take notes; try to get the caller's remarks word for word
- Obtain answers to these following questions:
  - When is the bomb going to explode?
  - Where is the bomb right now?
  - What does the bomb look like?
  - What is the bomb made of?
  - What will cause the bomb to explode?
  - Who placed the bomb?
  - Why?
  - What is your name?
  - Where are you now?
- Try to keep the caller talking. If necessary, pretend difficulty with your hearing. Try to weave these general questions into the conversation:
  - What did you say?
  - I'm sorry, I didn't understand what you said.
  - How do I know this is not a joke?
  - What group do you represent?
  - Why are you doing this?
- After the call has been terminated, immediately notify management.

Table 16.2 Outside Call Checklist—Part 2

The caller was most probably:
- Male
- Female
- Child
- Teenager
- Middle aged
- Older person
- Young adult

The caller seemed to be:
- Sober
- Drunk
- Mentally disturbed
- Nervous
- Calm
- Excited
- Angry
- Emotional

Table 16.2 Outside Call Checklist—Part 2 *(Continued)*

- Rational
- Irrational
- Coherent
- Incoherent
- Sincere
- Righteous
- Determined
- Laughing
- Joking

The caller talked:

- Loudly
- Softly
- With a high pitch
- With a deep voice
- With a rasp
- With a nasal sound
- Fast
- Slowly
- Slurred
- With a lisp
- With a stutter
- Pleasant
- With good pronunciation
- With a disguised voice

The caller's language was:

- Highly educated
- Good
- Poor
- Profane
- Full of slang words or expressions (include them in comments)

The caller had an accent that seemed to be:

- Local
- Not local (___________)
- Foreign (_________)

The caller seemed to be familiar with the Company:

- Building
- Equipment
- Plans
- Operations
- Personnel

Background noise:

- Party noises
- Bar sounds

(*Continued*)

Table 16.2 Outside Call Checklist—Part 2 *(Continued)*

- Another person or persons
- Music
- House sounds
- Animal sounds
- Street sounds
- Airport sounds
- Trains
- Factory machines
- Office machines
- Voices
- Quiet
- Other: ________________

The origin of the call seemed to be:

- Local
- Long distance
- Car phone
- From a mobile phone
- From within the building

Caller's remarks—word for word where possible

CHAPTER

Common hazards

17

CHAPTER OUTLINE

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INTRODUCTION

One of the philosophies that lies behind Process Safety Management (PSM) is that each chemical process is unique. Therefore, it is not possible to have a prescriptive standard that tells design and operating companies what to do. Instead, companies have to identify the unique hazards associated with their facility, and then implement corrective actions based on a risk-ranking methodology. For this reason, facilities covered by PSM standards have to conduct Process Hazards Analyses (PHAs), often using the Hazard and Operability (HAZOP) methodology. (The various PHA techniques are discussed in *Process Risk and Reliability Management.*)

Yet many process hazards are not unique: technologies, equipment types, and management styles tend to be quite similar between alike plants and companies, particularly within specific industries. Hence, many of the hazards that exist on these facilities are also quite similar to one another. Some of the more commonly observed hazards are discussed in this section; they are grouped into the following categories:

- Process hazards
- Hazards of utilities
- Hazards of water
- Hazards of steam
- Hazards of ice
- Hazards of compressed gas
- Hazards of air
- Hazards of external events
- Hazards of equipment and instruments
- Hazards of piping, valves, and hoses

PROCESS HAZARDS

Some of the more commonly identified issues to do process operations are shown below. They are organized by the HAZOP guidewords.

HIGH FLOW

Generally, the phenomenon of "High Flow"—in and of itself—is not inherently hazardous. Indeed, high flow rates are often desired because they imply that the facility is maximizing production and revenues. Although high flow can occasionally create hazards, such as erosion of pipe walls or of a valve seat, its main effect in terms of process safety is to create secondary deviations such as "High Level" in a tank. "High Flow" can also create a "No Flow" situation; e.g., if a pump overspeeds, the sudden surge in motor amperage may result in the motor burning out, thus leading to the flow stopping.

LOW/NO FLOW

As with "High Flow," the phenomenon of "Low Flow" is not usually inherently hazardous. However, it can create secondary effects. For example, a low flow of cooling water in a heat exchanger can lead to "High Temperature" of the process stream. "No Flow" is usually more serious than "Low Flow" because its occurrence implies a sudden cessation of a processing activity. Probably, the biggest hazard associated with "No Flow" is the possibility of it being followed by "Reverse Flow" because the upstream and downstream pressures have equalized or even reversed.

Both "Low Flow" and "No Flow" are usually caused by the inadvertent closing of a valve or the failure of rotating equipment such as pumps and compressors. Because such events occur quite frequently, most facilities have plenty of instrumentation and safeguards to respond to these scenarios.

REVERSE FLOW

"Reverse Flow" can create high-consequence hazards because it can lead to the mixing of incompatible chemicals or to the introduction of corrosive chemicals into equipment not designed for them. The cause of "Reverse Flow" is usually a pressure reversal — a high-pressure section of the process loses pressure; process fluids then flow into that section back from low-pressure sections of the process. (The occurrence of reverse flow almost invariably implies that a check valve and/or safety instrumented system has failed to prevent the event.)

"Reverse Flow" can lead to "Contamination." For example, Figure 17.1 shows a process consisting of three sections: A, B, and C. The chemicals in Sections A and B are noncorrosive, so these two sections can be safely made of carbon steel. When the two chemicals are mixed in Section C they react to form a corrosive product, hence this section has to be made of stainless steel. If a reverse flow

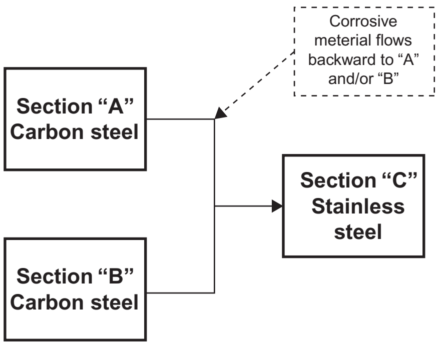

FIGURE 17.1

Reverse flow scenario.

should occur from Section C to either A or B, then those sections would corrode, leading to loss of containment.

Another feature of "Reverse Flow" to watch for is that it may take some time for the operators to identify its occurrence, particularly if the flow measurement instrumentation is not set up to recognize the phenomenon. Moreover, experienced operators frequently have trouble visualizing "Reverse Flow." They recognize the possibility of high and low flow because they have probably witnessed these events but reverse flow may be totally outside their experience. Hence, when the topic of Reverse Flow is being discussed during a HAZOP, the team leader should allow plenty of time for the team members to think through possible causes and consequences.

MISDIRECTED FLOW

"Misdirected Flow" occurs when a process stream is sent to the wrong destination. Like "Reverse Flow," this deviation can create high-risk scenarios because incompatible materials may be mixed with one another, or corrosive chemicals may be sent to areas not designed for them. Also like "Reverse Flow," this scenario may be difficult to detect or diagnose.

HIGH PRESSURE

"High Pressure" is a cause of many serious events. Some of the causes of "High Pressure" are listed in Table 17.1. For "High Pressure" to create an incident, it is likely that a protective interlock system failed and/or that the system's pressure relief valves did not function properly. The worst case is selected for the design of the relief device.

One special cause of high pressure is the explosion caused by near instantaneous evaporation of liquid through contact with hotter liquid. This may occur, for example, if very cold LNG (liquefied natural gas) comes into contact with water. The very high LNG vaporization rate can lead to an explosion. Such an event could occur during LNG transfer between an onshore terminal and the LNG carrier.

HIGH TEMPERATURE

As process temperatures increase the metal walls of pressure vessels will weaken thus reducing the maximum allowable working pressure (MAWP). (If the equipment of piping is made of synthetic materials, high temperature may lead to a sudden failure.) Hence a very high temperature, such as would occur in a runaway reaction, could lead to vessel failure at quite low pressures. Therefore, MAWP values should always be quoted with a corresponding temperature value.

Some of the causes and consequences of "High Temperature" are discussed below.

Table 17.1 Some Causes of High Pressure

- External fire impacting a vessel or piece of equipment
- Low flow out of a vessel
- High flow into a vessel
- Chemical reaction inside a vessel
- Blocked outlets
- Blocked-in pump
- Blocked-in compressor
- Connection to a higher pressure system and control system failure
- Overfilling of storage or surge vessels
- Utility failure
  - Electric power
  - Instrument air
  - Cooling water
  - Steam
  - Fuel (gas or liquid)
- Loss of cooling capacity
- Loss of quench
- Loss of absorbent flow
- Failure of air-cooled heat exchanger
- Failure of water-cooled heat exchanger
- Cold side of an exchanger blocked in while the hot fluid continues to circulate
- Failure of heat recovery system
- Loss of cold feed
- Failure of the flow of reflux or a side stream to a tower
- Excessive heat added
- Exothermic reaction
- Abnormal vapor input
- Loss of absorbent flow
- Excess volatile materials in liquid
- Accidental mixing of hot oil with volatile liquid such as water or light hydrocarbons
- Accumulation of noncondensibles
- Heat exchanger tube leak
- Another source of high pressure raising a relief or vent header pressure
- Thermal expansion of trapped liquids

Blocked-in pump

If a centrifugal pump is blocked in while it is still running the liquid trapped within the pump will heat up due to the energy that is being added by the rotating impeller. Sometimes, the rise in temperature will cause the pump seal to leak thus dissipating the pressure at the pump without creating a major hazard. In rare cases, however, the liquid in the pump may boil or react, thereby generating sufficient pressure to rupture the pump casing. Various case histories are discussed by Giles (2001).

Polymerization

The inadvertent polymerization of a chemical in a vessel can cause an explosion were it to occur rapidly enough. Even if the polymerization occurs relatively slowly a hazard can be created, particularly if the system safety relies on the presence of an inhibitor that is mixed with the chemical. In this scenario the chemical evaporates as heat is added (either from an external source or from a runaway reaction). The inhibitor remains in the liquid phase; hence the vapor that is formed does not contain any inhibitor.

The chemical then starts to polymerize, creating high temperature and pressure. Also, the vapor may condense on the upper surfaces of the vessel—including the internals of the relief valve—and polymerizes, thus disabling a critically important safeguard.

Some chemicals may degrade exothermically if they are isolated and then exposed to heat. This may happen, e.g., if a tank car containing one of these chemicals is isolated on a railroad track for a number of days in the middle of summer. If the chemical reaction is suppressed through the addition of an inhibitor, it is necessary to make sure that the inhibitor is not consumed.

External fire

A fire on the outside of a vessel can cause the vessel's internal temperature and pressure to rise rapidly leading to possible vessel rupture due to weakened metal. Relief valves are usually designed to handle the pressure rise caused by external fire. However it is useful to check that there are no unusual external fire situations that might overload the relief valve and that may have not been considered in the design. A particular concern is the potential for overlooked two-phase flow through the relief valve. Some facilities are designed on the assumption that external fire is implausible. If the only materials being processed are nonflammable, and if the plant equipment is constructed only of steel and other nonflammable materials, it can be argued that external fire cannot occur. Although ASME code does permit pressure vessels not to have relief valves in such situations, the hazards analysis team should thoroughly and carefully challenge all the assumptions behind the statement, "external fire is not plausible."

LOW PRESSURE

Low pressure poses a major hazard for storage tanks. These tanks are not designed to handle any significant external pressure and are easily "sucked in" hence they are generally provided with a vacuum breaker. As the pressure in the tank falls, so air (or an inert gas) enters the tank to maintain ambient pressure. (Causes of low pressure include pumping out liquid in the tank or a sudden condensation of process vapors during a rainstorm.) If the vacuum breaker is blocked by something as ordinary as a piece of flexible plastic the tank can fail catastrophically (CEP, 2007).

LOW TEMPERATURE

"Low Temperature" usually does not represent a safety threat to a process. Like "Low Flow," a reduction in process temperature will often lead to production losses, but rarely to unsafe operations.

One important exception to this observation concerns the cracking of carbon steel at low temperatures. Although low temperatures generally enhance metal strength (and so raise MAWP), very low temperatures may cause sudden and catastrophic embrittlement, particularly in cryogenic services. For example, carbon steel equipment and pipe is liable to fail—even when there is no load on it—if its temperature falls below $-20°C$. This phenomenon can occur, e.g., if a cryogenic liquid such as liquid air enters a carbon steel flare header.

Low boiling point liquids may cause autorefrigeration during emergency venting. Propane boils at approximately $-43°C$ and ethane at $-85°C$. Since ordinary carbon steels become brittle at these temperatures Deethanizers, Depropanizers and vessels containing similar liquefied gases may require special low temperature steels to withstand autorefrigeration temperatures associated with emergency venting.

Embrittlement problems can be addressed by using a higher grade of steel. Equipment in cryogenic service and with heat-sensitive insulation should be protected with fireproofing insulation to keep heat-sensitive insulation below degradation temperature.

HIGH LEVEL

The deviation "High Level" is important, particularly with regard to storage tanks, because it can lead to an immediate overflow of a hazardous chemical on to the ground or into a drain system. A particular difficulty with this deviation is that there is often little guidance as to the value for the Safe Upper Limit. Sometimes, operations management will choose to run a tank up to almost 100%, even though the chance of a spill becomes high.

A second issue regarding High Level is that many tanks are not adequately instrumented and may lack automatic alarm or interlock functions.

WRONG COMPOSITION

Processes that handle light hydrocarbons can suffer from a buildup of noncondensible materials. For example, if liquid propane is added to a pressure vessel, a vapor space will form at the top of the vessel. If the propane contains a small amount of noncondensible gas such as nitrogen, that gas will accumulate in the vapor space. If the vessel is then partially emptied and then refilled, additional noncondensible gases will be added to the vapor space. If this process is repeated a sufficient number of times, the concentration of noncondensible gas becomes high. This phenomenon could be hazardous if the added gas contains oxygen, or some other component that could react with the contents of the vessel.

A flammable vapor space (CCPS, 2001) can also develop in vessels which contain only trace amounts of flammable materials. This can occur in the following ways:

- A reaction involving a chemical with trace quantities of a flammable material; when the main component is consumed in the reaction, these small quantities accumulate in the vessel's vapor space
- A liquid containing small quantities of soluble or entrained flammable impurities flows through a vessel, the flammable material is released and trapped in the vapor space
- Adsorption of a liquid which contains trace quantities of a nonabsorbed flammable impurity which can be left to accumulate in the vapor space.

A related phenomenon can occur with heavy materials. If liquid containing a small amount of heavy contaminant is vaporized then the residual liquid at the bottom of the vessel will gradually accumulate heavy end components that could cause undesired chemical reactions or corrosion of the equipment in which they are contained.

CORROSION

Corrosion can be either uniform or localized. Uniform corrosion occurs evenly over a large metal surface and can involve large metal loss; hence, the equipment involved may lose a considerable amount of mechanical strength. Localized corrosion is evident through the appearance of pitting and crevice attacks; it can lead to the creation of stress corrosion points.

Uniform corrosion can usually be predicted and monitored. Therefore, even though the ultimate consequence associated with this type of failure can be high, it is unlikely to be a serious problem in practice because corrective action can be taken in plenty of time. Localized corrosion is more difficult to monitor and predict—thus it can often present a higher risk.

On large facilities, it is sometimes found that different processing sections possess different electrical potentials. Such a situation can lead to one of those sections suffering from serious corrosion. Examples of this phenomenon can be found on floating production facilities offshore (where the topsides have a different potential from the marine systems), and onshore pipeline systems, where the compressor and pumping stations can have a different potential from the buried mainline pipe. One means of preventing this problem is to install cathodic protection, i.e., to put an impressed voltage on one part of the system so as to change its potential and reduce the corrosion.

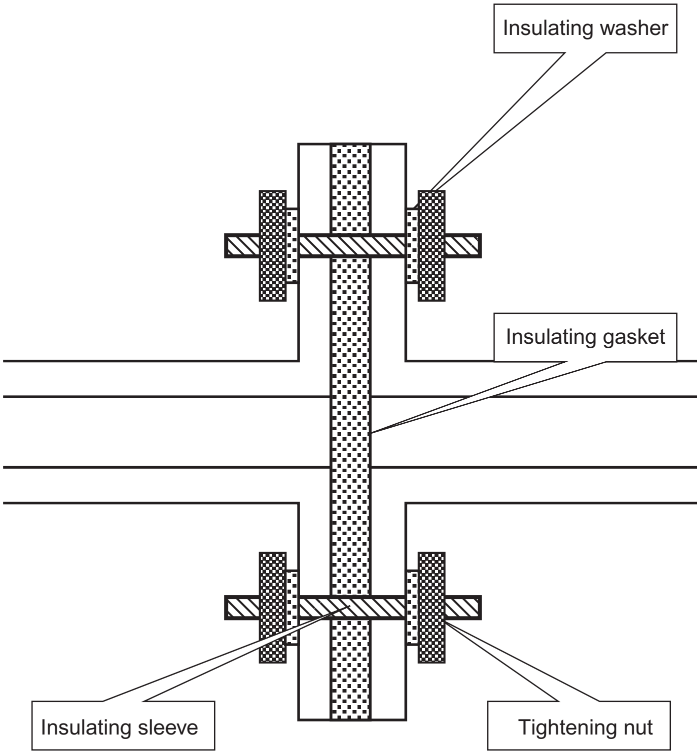

FIGURE 17.2

Insulating flange.

The different sections can be electrically isolated from one another by putting insulating gaskets between the flange faces, and by placing insulation under the nuts on the flange bolts as shown in Figure 17.2. From a safety point of view, the insulation system presents a difficulty. If the insulating gaskets and bolt sleeves are exposed to the high temperature associated with a fire they could fail, leading to flange separation which in turn would cause more fuel to feed the fire.

CHEMICAL EMBRITTLEMENT

A cause of sudden and catastrophic failure is chemical embrittlement. This occurs when the wrong chemical enters the vessel or pipe, and causes it to fail in a very short period of time. Examples of embrittlement include the effect of caustic on stainless steels and hydrogen on various types of steel. Chemical embrittlement is particularly serious because it can happen to new equipment as easily as old, and because it may give little or no warning that it is about to occur.

STRONG OXIDIZERS

The Process Safety Beacon (CCPS, 2013) warns of the dangers associated with strong oxidizers such as sodium permanganate. If inadvertently mixed with reducing agents such as sodium thiosulfate, even in small quantities, an exothermic reaction will occur. The heat generated may be sufficient to create a serious hazard.

STATIC ELECTRICITY

One of the hazards that must be guarded against in handling petroleum products is accidental ignition by static electricity. Tank car and tank truck loading operations involving distillate products, under certain conditions, are particularly vulnerable to static ignition (as discussed in Chapter 15).

HAZARDS OF UTILITIES

Utility systems can create many difficult-to-predict hazards because they connect many different sections of a process. Issues to do with utility-related hazards are discussed later.

COMMON CAUSE FAILURE

The first and most obvious problem to do with utilities is that their failure will create simultaneous problems throughout the facility. They generate common cause effects. For example, were oxygen to enter a nitrogen header a fire or explosion hazard could be created in other parts of the plant or facility.

PROCESS CONTAMINATION

A second, and more subtle, problem to do with utilities is their potential for process contamination. On one refinery, e.g., the highly toxic and corrosive chemical hydrogen fluoride (HF), which is discussed in Chapter 5, leaked into the instrument air system. This had the effect of spreading HF all around the refinery; it was even being vented from instrument lines in the control rooms.

When a leak occurs between the process and one of the utility systems, it is often difficult to track down the source of the leak. For example, it is quite common to place a hydrocarbon detector in the plume from a cooling tower. Then, if one of the process coolers or condensers leaks, the detector will detect the presence of hydrocarbons. The difficulty lies in knowing which of the equipment items is leaking.

ELECTRICAL POWER FAILURE

Failure of the electrical system can lead to "High Pressure" in those cases where the utility is removing energy from the process. For example, an overhead fin-fan on a distillation column may serve to condense the overhead vapors from that column. Loss of power will cause the vapors to pass through the condenser without being cooled or condensed, thus creating a high-pressure situation.

Loss of power can also cause critical instruments to shut down. These instruments should be backed up with an uninterruptable power supply (UPS).

NITROGEN

Nitrogen has many uses on process facilities, including the inert gas blanketing of tanks, equipment purging, and as a carrier for catalyst regeneration. Oxygen contamination of the nitrogen system must be avoided as such because contamination could create a mixture that is no longer an inert medium.

Its availability in large volumes in many facilities also allows for its use as an emergency source of instrument air. However, this practice can have serious consequences. Instrument air systems often vent or leak into confined areas—the presence of nitrogen could create a serious breathing hazard. It is suggested that the following guidelines be considered when using nitrogen to back up the instrument air supply.

- Do not allow permanent connections between the nitrogen system and either the plant or instrument air systems.
- Utility nitrogen stations should be clearly marked and have special connectors and hoses which are not common to any other system. Universal air hose connections (crow's foot) should not be used in nitrogen service.
- Locations where backup nitrogen is being used should be monitored and alarmed for low oxygen concentration, and signs and barriers installed.
- Once the problem with the instrument air system has been resolved, the nitrogen to instrument air cross connection must be removed.

REVERSE FLOW TO A UTILITY HEADER

The hazards associated with (unexpected) reverse flow can be very serious. One particularly troublesome reverse flow scenario is "Reverse flow to a utility header" as illustrated in Figure 17.3, which shows two lines. The top line is a utility such as nitrogen, steam, or service air. The lower line shows a process stream containing a hazardous chemical. In normal operation, the utility flows into the process through a check valve (with block valves on either side of it).

The hazard scenario is as follows:

- The pressure in the utility header falls (say due to an operating upset) so that it is lower than the pressure in the process line.

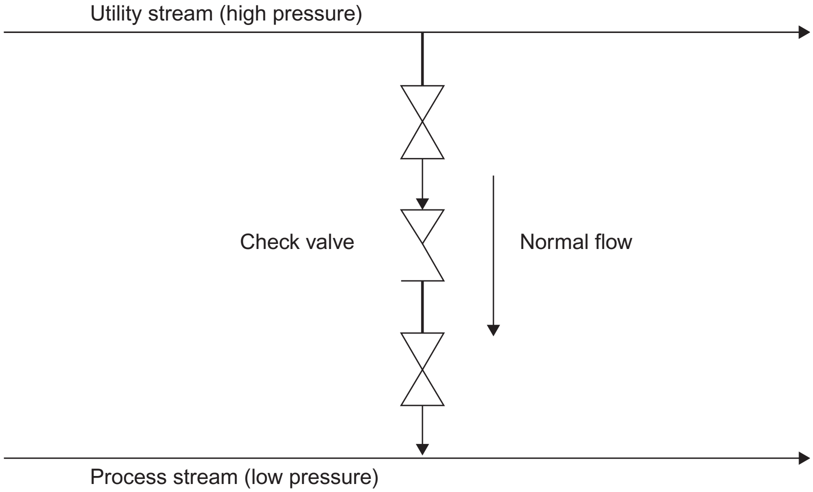

FIGURE 17.3

Reverse flow to a utility header.

- The check valve fails to fully close.
- Process chemicals flow into the utility header from the process line.
- Process chemicals are then distributed to many other locations in the facility via the utility header.

To make matters worse, this scenario is "memory less," i.e., once the pressures revert to normal there is no indication as to what happened. Identification of the source of the contamination can be particularly difficult if the process chemical that has entered the utility header is used in many parts of the overall process.

SURVIVABILITY OF UTILITIES

Many utilities must survive a catastrophic event such as a major explosion or fire so that emergency response systems continue to function. Yet such an incident can destroy critical utilities header containing electrical cables, cooling water lines, and steam pipes. This is a very serious common cause effect that can trigger domino events that lead to a major catastrophe. The effect is magnified if emergency systems such as the firewater header are also damaged.

HAZARDS OF WATER

Water is not normally thought of as being a hazardous chemical. However its ubiquitous nature, and some of its unusual physical properties, means that it can create significant safety problems, some of which are discussed below.

WATER IN HYDROCARBON TANKS

In refineries and other facilities that process hydrocarbons, storage tanks may develop a layer of water below the hydrocarbons. The water typically enters the tank in small quantities, phases out, and settles at the bottom of the tank. The water can enter the tank with the process streams, through leaks in steam coils, and through leaks in the tank roof and open hatches. Sometimes, the water will create an emulsified product with the hydrocarbons. This product is referred to as a "rag layer" or "bottoms sediment and water" (BS&W).

If the tank level is allowed to drop to too low a level this inventory of water may be suddenly pumped into the process itself, thus creating a hazardous situation. For example, the dense water could cause a downstream pump to suddenly shut down. BS&W and water layers can pose a particular problem when switching tanks. If a process unit is taking feed from one tank, then the operator switches to a second tank, thereby the process could suddenly be hit with a slug of water and/or BS&W.

Also, any vaporization of water below the surface of hot, heavy oil can lead to the formation of foam, with the foam having a volume some 20−30 times as great as the oil of which it is composed. If the foam overflows the tank in which it is formed then "foamover" has taken place.

WATER IN VERY HOT LIQUID

If water is trapped in a confined space and then heated to a temperature well above its boiling point, a violent physical explosion will occur. Such an explosion can occur if water is trapped under a layer of very hot oil. For example, a tank may contain a residual heel of water following a plant turnaround. If, on start-up, very hot oil is pumped into the tank the water will reach a temperature far above its boiling point but will not immediately form a vapor because the liquid covering it suppresses boiling. However, when the water does vaporize it will expand very rapidly and create very high pressures. Storage tanks are not designed for these pressures and so may disintegrate.

An example of this type of hazard (created by adding firewater too quickly) is provided by the Center for Chemical Process Safety (CCPS 2003).

The dangers of adding hot hydrocarbons to water are part of the broader topic of what is referred to as rapid phase transition, the necessary criteria for which are as follows:

- The two liquids must be immiscible.
- The liquids must be at very different temperatures.
- The cooler liquid must be the more volatile of the two.
- The cooler liquid must be confined—either in some type of container such as a can or by the hot liquid above it.

If these conditions hold the hot liquid can heat the cooler liquid to about 0.89 of its critical temperature value. At that temperature, the cool liquid can nucleate and explode.

The metals industry faces a similar phenomenon. For example, a high percentage of used aluminum products are recycled by being added to a vat of molten aluminum. If water is present in the recycled material (for example, an aluminum can may still contain liquid) a violent explosion can occur. This event is sometimes referred to as a "steam trap" explosion. The Aluminum Association has outlined the following mechanism for such an explosion:

- Virtually instantaneous change in the state of the water from a liquid to a gas
- Containment of the gas by the liquid metal causing the pressure of the gas to rise at an extremely rapid rate
- Buildup of pressure of the gas until it no longer can be contained by the molten metal
- Explosion of the hot gas, with damage being caused by the shock wave and by the molten metal being sprayed over a wide area.

WATER AND FIREFIGHTING

Water is a vital firefighting medium. However, the use of water to control fires does have associated hazards, including the following:

- Uncontrolled flow of water away from a fire can transport burning liquids to other parts of the facility.
- The high conductivity of water can make its use dangerous near high-voltage equipment or power lines.
- The sudden application of cold water to hot piping or vessels can severely reduce the strength of the steel—even crack it (a critical factor in the Esso Longford incident).
- Water may flood relief and vacuum vents.

HAZARDS OF STEAM

One of water's greatest hazards is the volumetric expansion (and corresponding pressure increase) that takes place when it is transformed into steam. For example, at its boiling point of 100°C water vapor occupies a volume 1,600 times that of the corresponding liquid. Many of the hazards of steam discussed below are so serious because of this very large volumetric expansion.

STEAMING VESSELS DURING TURNAROUND

After a piece of equipment, such as a heat exchanger or a distillation column, has been inspected or repaired, it is a common practice to steam out that item prior to its restart. The steam helps clean the metal surfaces of residual maintenance materials (such as oil) and also removes oxygen (air) from the vessel. On completion of the task, some of the steam that was present in the system will condense; the resulting water will collect at low points in the system, behind orifice plates, above horizontal valve bodies, in trapout trays, and in vessel bottoms. Where possible, low-point bleeders should be installed so that the trapped water can be drained. However, it is not possible to place bleeders at all low points; also bleeders have a tendency to plug—particularly if they are only rarely used. Therefore, it is very likely that, on restart, the process will contain residual water at various locations. If heated by the process fluids, the water vapor that is formed could cause considerable damage. Moreover, if the water vapor then condenses in another part of the process a vacuum could be created with the attendant danger of implosion.

To reduce the hazards associated with water accumulation, a common practice is to start the commissioning process by circulating oil or hydrocarbon around and through all of the equipment, then gradually heating the circulating oil. Any water is swept out of the pockets where it has accumulated and gradually evaporated as the oil heats up.

REBOILER LEAK

Many distillation columns are heated by steam reboilers. Typically, the process materials are on the tube side of the exchanger with the steam being on the shell side, as shown in Figure 17.4.

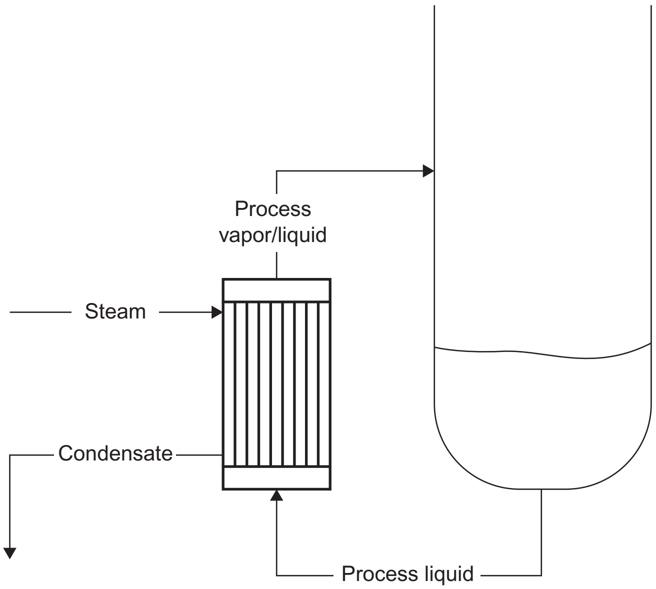

FIGURE 17.4

Representative reboiler arrangement.

If the steam is at higher pressure than the process (which is frequently the case) and if one of the reboiler tubes develops a leak, steam will enter the process and flow up the distillation column. Given that the water has a much lower molecular weight than most chemicals that are being distilled, the volumetric flow of gas up the column can be so large that the trays or packing in the column are lifted up off their supports and seriously damaged.

WET STEAM IN TURBINES

Condensed steam must be drained from a turbine before it is put into service. Droplets of water moving at high velocities in a supposedly dry steam line can destroy a turbine or compressor wheel. Similarly, the presence of (incompressible) water in a reciprocating compressor can lead to the destruction of the machine.

HAZARDS OF ICE

Ice is obviously hazardous in a day-to-day sense because it can cause people to slip and fall. But ice (and ice compounds) can also be hazardous from a process point of view. Particular concerns are to do with line freezing and hydrate formation.

LINE FREEZING

If a line contains water that is either not flowing, or is flowing very slowly, below-freezing ambient temperatures can cause the water in the line to freeze and expand. Therefore, during cold weather, equipment and piping that is not in use should be drained and blocked in if it cannot be heat traced.

HYDRATES

Hydrates are complex solid compounds that are formed at low temperatures from organic materials (either gas or liquid) and water or aqueous solutions, such as brine. Hydrates often look like dirty snow or ice. Being solid, hydrates can create major operating and safety problems because they can plug heat exchanger tubes, oil production flow lines, and instrument lines. Because hydrates form at low temperatures, they will generally disassociate back to the original hydrocarbon and water if they are warmed up. Hydrates can also be removed from process lines by adding methanol to the flowing stream. The methanol dissolves the hydrate solid.

HAZARDS OF COMPRESSED GAS

Compressed gas has caused many accidents. Two types of compressed gas hazard are discussed below: the dangers associated with compressed gas cylinders and the hazards to do with using compressed gas for pigging.

GAS CYLINDERS

All compressed gases are hazardous because of the high pressures inside the cylinders. Gas can be released deliberately by opening the cylinder valve, or accidentally from a broken or leaking valve or from a safety device. Even at a relatively low pressure, gas can flow rapidly from an open or leaking cylinder. If the leak is severe enough the damaged cylinder behaves like a rocket or pinwheel.

PIGGING INCIDENT

The following incident is based on an unauthenticated report of serious near-miss involving the use of compressed air. The reported sequence of events was as follows:

- A 10-mile section of line was being dewatered following a hydrostatic test. A foam pig driven by compressed air was used to displace the water. The water was being removed from a 12″ bypass line.
- The pig got stuck; the gas pressure was increased until it reached approximately 400 psig. The end of the temporary trap was also opened up.
- At this point, the pig was seeing downstream pressure of ambient and an upstream pressure of 400 psig. The differential force was enormous.
- In order to catch the pig, a large front-end loader was placed in front of the open trap.
- The pig shot out of the trap, flipped the loader and continued to fly approximately 150 yards in the air, destroying a wooden platform along the way and flipping a front-end loader on to its side.

Fortunately, all personnel had been removed from the area so there were no fatalities.

This incident can be used to highlight safety procedures regarding pigging. However, it also illustrates the tremendous forces that can be generated by compressed gases.

HAZARDS OF AIR

Because it is a substance that everyone breathes all the time, air is rightly perceived as being benign. However, air does pose some hazards on process units, mostly due to its oxygen content, which is an oxidant for hydrocarbons and other materials that burn. If air enters a process that contains flammable hydrocarbons and/or reducing chemicals, then a serious accident could ensue.

FLAMMABLE MIXTURE

Air can enter a process in one or more of the following ways:

- Through open lines and vessels
- With a process stream or with wash water

- Leakage into vacuum systems—say through an open bleeder
- Leakage through open or defective valves
- Atmospheric air entering a vessel or tank when liquid levels are lowered
- Compressed air leakage into a process from a compressor or blower
- Compressed air used in line blowing
- Compressed air used for agitation
- Air in solution in feedstocks or products
- Failure to purge a system properly following a turnaround
- Air used in oxidation processes
- Air contamination of nitrogen or other compressed gases used for purging or processing

Air dissolved in a hydrocarbon stream such as propane can be particularly dangerous. If the stream is pumped into a storage vessel, some of the propane and oxygen in the air will vaporize. Being more volatile than the hydrocarbon, the oxygen content in the vapor space will be higher than it is in the liquid. If some of the liquid is pumped out, and then replaced, the concentration of oxygen in the vapor space at the top of the tank will gradually build up—possibly to dangerous levels.

For these reasons, all vessels, which can have a vapor space in which air can accumulate, should be checked on a regular basis for oxygen. If significant oxygen concentrations are found to be present, then the vapor space should be purged with an inert gas such as nitrogen.

BLOWING A LINE CLEAR

If a pipeline becomes plugged with a solid obstruction, it can be blown clear with high-pressure gas. It is important not to apply too much pressure to the obstruction, otherwise, when it does move, it will become like a missile within the pipe. One company plugged a transmission line with hydrate. They then applied a very high pressure to the pluggage, with just atmospheric pressure on the other side. The hydrate plug did break free; it raced down the line, and then hit an elbow. Its momentum was so great that the elbow was ruptured, and a worker was killed.

HAZARDS OF EXTERNAL EVENTS

External events are those events that are totally outside the control of the facility management. Some of the more important external events are discussed below.

FLOODING

Many process facilities are built at the seacoast or on rivers so that they can import and export bulk products by barge and ship. However, this proximity to water means that they are vulnerable to flooding in the event of storms and high tides.

The resulting high water causes equipment throughout the facility to fail simultaneously. The water also can cause toxic chemicals in open drains and other parts of the plant to float into other areas, thus creating serious environmental problems.

It is likely that problems associated with flooding of facilities located close to the coast will grow as the climate continues to warm.

LIGHTNING

Lightning is an obvious source of ignition particularly for open hydrocarbon vents. Lightning flashes can also be interpreted by fire detection systems as being an actual fire, thus initiating a full, and unnecessary, shutdown of the system. (Modern fire detection systems are able to distinguish between the wavelengths of fire and lightning radiation.)

Earthquakes

Earthquakes (and tsunamis) pose a great danger to process plants. An earthquake can cause equipment items to collapse, lines to rupture, and tanks to fail. For this reason, the construction codes used in seismically active areas are very strict. One item to watch for in particular is a situation where an earthquake causes a major leak of flammable materials and also destroys the firewater header.

HAZARDS OF EQUIPMENT AND INSTRUMENTS

Hazards to do with specific equipment items and with instrument systems are discussed in this section.

FURNACE FIRING

The lighting of fired heaters always has the potential to create an explosion. Two issues are of particular concern. The first is that the firebox is filled with a flammable mixture of hydrocarbon gas and air (oxygen). If a burner is ignited, an explosion will occur. The second concern is that a furnace is operating normally, and then the fuel gas supply fails thus causing the burner flames to go out. If the fuel gas supply is then restored, an unburned mixture of gas and air can enter the hot firebox and ignite.

FIRED HEATER BURNOUT

Fired heaters rely on the flow of process fluids through the tubes to keep the tube and firebox temperature down. How this is done is with a control system such as that shown in Figure 17.5. If the temperature of the process fluid leaving the

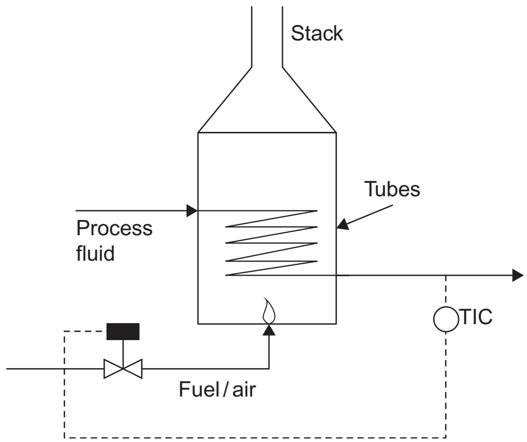

FIGURE 17.5

Control of a fired heater.

heater falls, the TIC (temperature indicator controller) calls for more fuel to be fed to the burners.

The difficulty with the above arrangement arises if the flow of process fluid is stopped for any reason the outlet temperature will fall, thus causing the flow of fuel to be increased. However, without the flow of process fluid there is no means of removing the heat that is being added (rather like putting an empty kettle on a stove). Hence, the tubes will get hotter and hotter until eventually they fail (or the catalyst that is in them is irreversibly damaged).

One solution to the above problem is to put a flow measuring device on the fluid stream. If the flow of process fluid falls below a threshold value, the heater will be automatically shut down.

MULTIPLE USES OF EQUIPMENT

When equipment items are used for more than one purpose there is a chance that a high-consequence hazard may be created. For example, on one plant certain storage tanks were used to store a liquid that could freeze at ambient temperatures. Therefore, the tank contents were heated with internal steam coils. However, during turnarounds, the tanks were used to store another chemical. This second chemical was a monomer that could not freeze at normal temperatures and that could, if heated, polymerize rapidly and exothermically. Consequently, if during the plant restart the operators omitted to clear the tanks of this second chemical before turning on the steam coils, the chemicals in the tanks could polymerize, leading to an accident.

DISTRIBUTED CONTROL SYSTEMS

Many plants are controlled by distributed control systems (DCSs). A DCS system consists of a set of cards or boards. Typically, about eight signals come from the plant into the board, as shown in Figure 17.6. The DCS circuitry processes the incoming signal and calculates one or more output signals which adjust control valve positions.

Figure 17.6 shows a card that has eight input and six output signals to controllers—there can be failure on the input side or on the output side. If there is a failure on the input side, two things will happen. First, the transmitted values to the DCS screen will disappear; the operator will have no knowledge as to what those values are unless someone goes outside to check. The second consequence of the failure of the input card is that the signals that it controls will fail, usually in their last position. Hence the control valves that are being controlled will "freeze" in place (fail last position). Therefore, if the operation was running smoothly before the input side of the board failed, there should be no sudden change in the operation. However, it is important for the hazards analysis team to make sure that the output signals do fail in their present condition. If they cause the affected control valves to fail closed or open, the operation will be affected much more dramatically.

Failure of the output side of the DCS card is a more serious matter because generally all valves will fail in their safe position. This may sound acceptable, but it has to be remembered that the fail-safe positions for the valves were selected assuming that there has been a total system failure. The failure of just one board will lead to just eight control systems failing, with all the other valves on the plant in their normal operating position, thus creating unusual and possibly unsafe operations.

For example, a total system shutdown may cause a pump to stop and its discharge valve to close. In the case of a single card shutdown situation, however, it may be that the pump will continue to operate but that its discharge valve will

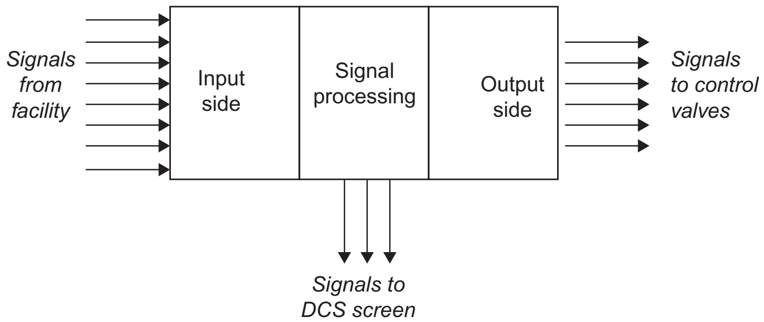

FIGURE 17.6

Sketch of a DCS card.

close thus causing the pump seal to leak. When evaluating such scenarios, there are three general rules to follow:

- Sections of the process that remove energy should continue to operate. These sections include cooling water systems and fin fans. Usually, the removal of energy from a process will move it toward a safer state.
- Sections of the process that add energy should be shut down. This includes steam and electric heaters.
- Sections of the process that contain large quantities of hazardous chemicals should be contained, i.e., the block valves around them should be closed, but the vent and drain valves may be opened, depending on the contents of the vessels.

A DCS hazards analysis, therefore, has two principal parts. First, it must evaluate the fail-safe condition of each valve, not only for a total system outage but also for a failure of the valves on the boards individually. Once this is done, the team should then evaluate the effect of a board failure on the rest of the system. One recommendation resulting from this analysis may be to move control loops from one board to another. In general, the components of a single system, such as a distillation column or a reactor, should be put together on one board.

HAZARDS OF PIPING, VALVES, AND HOSES

Some of the hazards to do with piping, valves, and hoses that are observed in many facilities are discussed below.

PIPING

Hazards associated with piping include the following:

- Pipe class transition
- Hydraulic hammer
- Pig launcher and receivers
- Pressure in relief headers
- Overload of vacuum lines
- Underground piping
- Vents and bleeders

Pipe class transition

When a pipe class changes, it is important to make sure that the lower grade of steel is not located too near the more severe service. For example, the transition from high temperature-to low temperature-rated pipe should not be so close to the higher temperature service such that the lower temperature line could be affected.

Similarly, it is important to ensure that hazardous chemicals cannot flow back into a lower pipe class zone.

Hydraulic hammer

Hydraulic hammer is created by stopping and/or starting a liquid flow suddenly. If the valve in line containing liquid is closed quickly, the entire volume of liquid in the line up to the valve is also stopped quickly. The effect is to create a sudden pressure surge that can damage instruments and valves, and, in extreme cases, cause the pipe itself to burst.

Hammer can also occur in lines containing process vapors or low-pressure steam. If the vapor or steam is cooled as it flows down the line liquid forms in the bottom of the line and then flows forward with the gas or steam. Eventually, the amount of liquid can be so great that it has the effect of blocking the line in the same way that a valve would do, thus creating the potential for hammer.

If hydraulic hammer is considered to be a potential problem and the valve causing the hammer is automatically actuated, consideration should be given to putting a restriction in the vent line from the actuator. This restriction would prevent the valve from closing too quickly.

Pig launchers and receivers

The use of pig launchers and receivers is inherently hazardous because they require that process piping be opened to the atmosphere and that operators be in the area (to insert and remove the pigs). Three hazards to do with these equipment items require particular attention. The first is that operators and maintenance personnel face the potential of being exposed to large quantities of toxic and flammable materials if the pigging equipment is opened prematurely. The second hazard is to do with the possibility of the pig accidentally shooting out of the launcher or receiver if the operation is not conducted properly. The third hazard is that, for larger lines, the act of lifting a pig to put it into a launcher (or to remove it from a receiver) leads to the possibility of the pig being dropped on to someone or something.

The risk associated with the above hazards can be ameliorated through the use of interlock systems and operating procedures that do not allow the pig trap/receiver door to be open while the system is under pressure.

With regard to the second hazard—the possibility of pigs impacting people or equipment—the risk can be minimized by ensuring that the trap/receiver is in a location away from normal operations, and that the doors should point to a safe location (on offshore platforms, the door should face outboard toward the ocean).

Pressure in relief headers

Relief valves have a set pressure at which they open. However, it is important to realize that actually it is *differential* pressure that opens the valve. Therefore, if the set point for a relief valve is say, 1 barg, and the pressure in the relief header is 0.2 barg, then the relief valve will open when the pressure in the vessel it is protecting is 60 psig. Such a scenario could occur if a plant-wide upset has caused multiple vessels to discharge into the relief header at the same time.

To get around this difficulty, some relief valves are designed to open at a specified *absolute* pressure. The PHA team should check which approach is being used in the facility that is being analyzed and should consider the implications of multiple relief valves opening simultaneously (such as would happen if there were a large fire on the unit).

Overload of overhead vacuum lines

High capacity vacuum distillation columns typically have very large diameter overhead lines from the top of the column to the condenser because the available pressure drop is so small. Also, because the system pressures are so low the piping wall can be quite thin. Therefore, if the line is inadvertently filled with liquid (either process liquids during a column upset or water during hydrotesting) the lines or their supports could collapse.

For these systems, special precautions need to be taken to ensure that the column cannot overflow. Also, a procedure for pressure testing the system with gas has to be developed and followed.

Underground piping

Underground piping can be hazardous because not much may be known about the condition of the piping: "out of sight, out of mind." The first indication of a problem may be contamination of the groundwater or some other pollution event. Moreover, the piping may be subject to unusually high corrosion rates if a cathodic protection system was not installed.

Vents and bleeders

A common hazard is the leak of a hazardous chemical from a vent or bleeder. Causes of the leak can include the following:

- The vent or bleeder is inadvertently left open (or not completely closed).
- The internals of the vent or bleeder valve erode or corrode, and leakage cannot be stopped.
- Someone working with the valve pulls it off the pipe to which it was connected (usually this requires corrosion to have weakened the join).

HOSES

Hoses are often involved in accidents because, in almost all cases, their use implies that a temporary or short-term operation is being undertaken. Sometimes, the operation is routine—truck loading and unloading, for example. In other situations, hoses are used in temporary operations such as the bypass of a leaking valve that is to be removed for maintenance. Whatever the reason for its use, there is the potential for a release of hazardous chemicals, particularly at the start and finish of the operation.

Hoses and truck pull-away

If a truck is connected to a process tank for loading or unloading, and the truck drives away before disconnecting its hose from the tank, chemicals could be released from the tank, from the hose itself, or from the truck. Safeguards to consider in these situations include the following:

- Secondary containment around the loading station
- Intentional weak spots in the loading system such that any spill will be directed to a safe location
- Excess flow valves on the truck and tank
- Special operating procedures, such as removing the keys from the truck until the operator has checked out the site.

Hose run over

If vehicle runs over a hose that is in use, the hose may split. Alternatively, the hose may be crimped, leading to consequences such as low flow or high pressure in other sections of the process.

Hose failure

Being flexible and subject to abrasion, hoses are subject to failure if not carefully inspected, maintained, and replaced. If hoses are to be stored outside, it should be confirmed that they cannot be damaged by water, freezing, or ultraviolet light from the sun.

Backflow preventor

When utility hoses are connected to a process, it is particularly important to make sure that a backflow preventor (check valve) is installed. Otherwise, hazardous chemicals may reverse flow through the hose into another operating area.

Temporary connection

A reverse flow incident involving a temporary hose connection led to an explosion and fire in which two people were seriously injured. A hydrocarbon system was to be cleaned using water. A hose was connected to the firewater system as shown in Figure 17.7. It was left overnight prior to starting work the next day. The hydrocarbon system was full of liquid at low pressure. The block valves shown were left open, even though they should have been closed. A temporary check valve was not placed in the hose line.

During the night the hydrocarbon header was pressured up by a pump about a mile away. Its pressure was greater than that of the firewater header so hydrocarbon liquid flowed into the firewater system. Through a series of underground

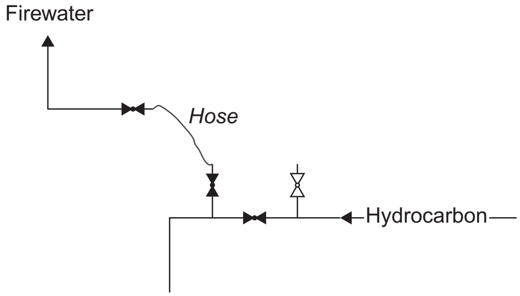

FIGURE 17.7

Reverse flow scenario through a hose.

connections, the contaminated water entered a maintenance workshop. Vapors accumulated and an explosion occurred.

VALVES

Some of the hazards associated with valves are discussed below.

Block valves below relief valves

Pressure relief valves are a critical safety item in almost all process facilities. Pressure relief valves simply must work. This means that they must never be blocked in from the equipment item(s) that they are protecting. Yet their very criticality means that relief valves will have to be routinely isolated and/or removed from the system that they are protecting so that they can be maintained and tested—both for the pressure at which they open and, more rarely, for their flow capacity.

Therefore, many companies permit a block valve to be placed beneath each relief valve. This allows them to block in the relief valve, remove it for testing and service, and reinstall it, without having to shut down the process. The hazard associated with this practice is obvious: if a high-pressure situation develops while the block valve is closed, the system could overpressure and rupture. For this reason, other companies prohibit the use of block valves below relief valves altogether.

If it is necessary to work on relief valves routinely, protection can be provided by installing two or more relief valves at each location. That way, one relief valve can be blocked in while the others provide protection.

A less satisfactory alternative is to provide a temporary means of relieving high pressure while the block valve under the relief valve is closed. One company, e.g., stationed an operator full time on the top of the affected vessel. He kept his eye on the outside pressure gauge, and, if the pressure rose above the safe limit, he was instructed to open a vent line to the flare header. Such a solution is inherently more open to failure, not least because it relies on the consistency of a human response.

The following guidance can help minimize the risk associated with having block valves below relief valves.

- A bleed valve should be installed between the relief valve and block valve. If a rupture disc is used between the block valve and the relief valve, the bleed valve should be installed between the block valve and the rupture disc.
- Full-port gate valves are the preferred type of block valve.
- Block valves should not be installed in any relief valve system of any boiler or steam generator constructed to the requirements of the ASME Boiler and Pressure Vessel Code, Power Boilers, Section I. Many state boiler laws also prohibit this practice.
- The block valves must be locked open when the relief valve is in service.
- The status of the block valves should be checked frequently.

When a relief valve is removed for testing, the vessel that it was protecting no longer has that safeguard against overpressure. Ideally, the equipment item will be shut down and opened to the atmosphere. In many facilities block valves are installed immediately below the relief valve. The block valve is normally in the open position (either car-sealed or locked). When the relief valve has to be removed for maintenance, the block valve is closed so that the system can remain in operation. (If a gate valve is used, it should be installed horizontally so that, where the gate to fall off the stem, it would not inadvertently block the line.) Some facilities use dual relief valves tied in to a three-way valve so that at least one relief valve remains in service at all times.

During the time that the vessel is operating in this manner, it is necessary to have some other means of protecting the vessel from overpressure. One way of doing this is to have an operator stand by a block valve that can be opened so as to depressure the vessel to a vent or flare. If he receives instructions from the control room, or if he notices anything amiss, he will immediately open this valve. The block valve should not allow more than 3% pressure drop; quarter-turn valves (e.g., plug or butterfly valve) should have a position indicator positively secured to the stem.

Whatever system is chosen, the pressure drop between the vessel and the relief valve is limited to 3% of the relief valve's set pressure.

Fail-safe control valves

Control valves on inlet, outlet, and reflux streams are crucial for overpressure protection during plant problems involving loss of utilities such as steam, electrical power, and instrument air. Normally, feed valves should fail closed; outlet and reflux valves should fail open. However, there are exceptions, and each situation must be individually evaluated during the PHA.

SHARED RELIEF VALVE

If two or more vessels share a single relief valve, there may be circumstances where one of the vessels has to be isolated from the relief system. In such cases, it is vital that a strict policy to do with locking valves in the correct position be followed. For example, in the case of Figure 17.8, Vessel A is in service, while Vessel B is isolated from the process but lined up to the relief system. Both valves 3 and 4 are locked open. Switching the process feed from A to B (by closing valve 1 and opening valve 2) does not require that any change be made to the relief valve lineup.

Figure 17.9 represents a much more hazardous situation. Vessel A is in use while Vessel B is blocked in and positively isolated for maintenance work—say to change out a catalyst bed. Valve 4 is closed in order to protect workers from a release from Vessel A. If an external fire occurs near Vessel B, it may be overpressured because it is isolated from the relief system. In such situations, Vessel B must be provided with another pressure relief mechanism or the vessel should be open to the atmosphere.

If one relief valve protects two or more vessels, the following rules should be followed.

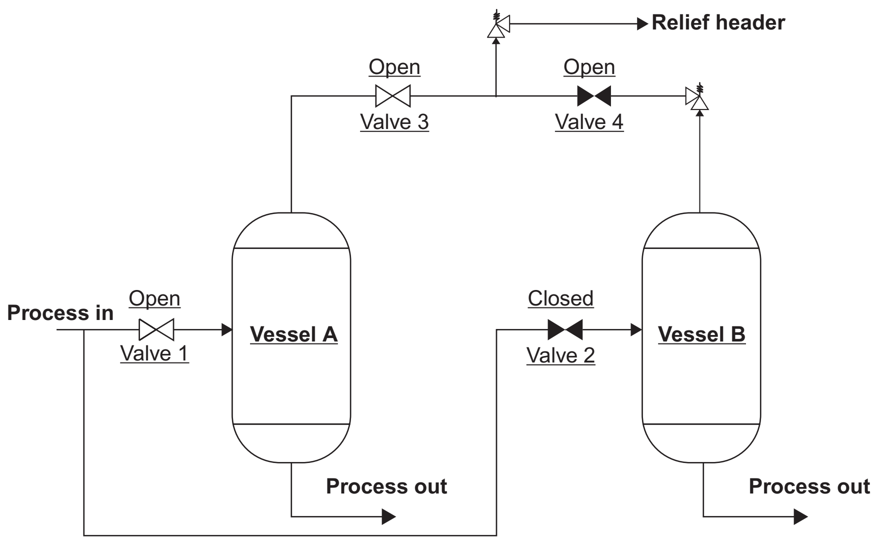

FIGURE 17.8

Two vessels—normal operation.

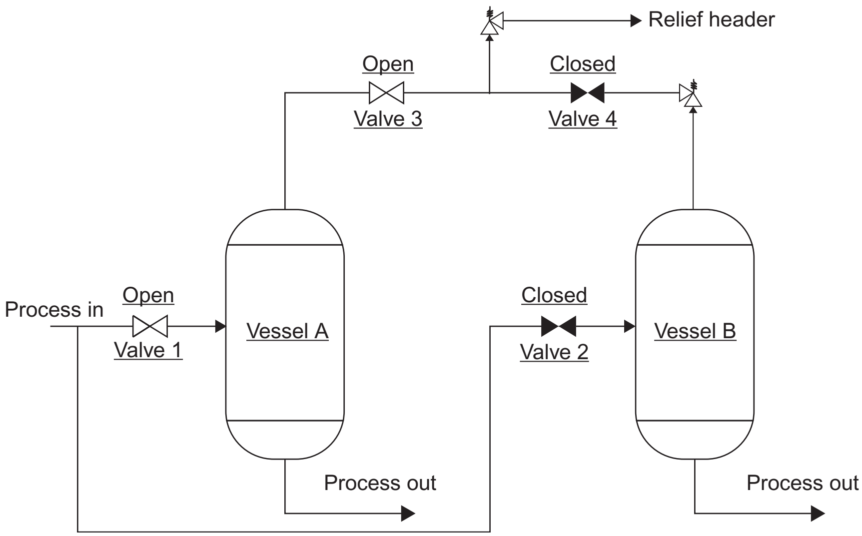

FIGURE 17.9

Two vessels—one isolated for maintenance.

- The relief valve capacity must be adequate to protect both vessels for applicable scenarios. The set pressure must be at or below the MAWP of the vessel with the lowest design pressure. Pressure losses through the piping must be considered.
- There are no valves, check valves, or automatic control valves that may inadvertently isolate the vessels.
- The gate valves that isolate the vessels must be a horizontal stem, manually operated, and locked open.
- The combined wetted surface—below 10 meters—of all the vessels connected to the single safety valve is used in computing heat input from fire.

SDV BYPASS

Following the shutdown of large emergency shutdown valves (SDVs), a high residual differential pressure across the valve may remain. This high differential pressure can make it hard to open the SDV, and, once it is opened, the resulting surge of high-pressure fluid may be sufficient to cause significant downstream equipment damage. Therefore, a small diameter manual bypass valve such as that shown in Figure 17.10 should be installed. It is opened before the SDV in order to equalize the pressures on each side of the SDV.

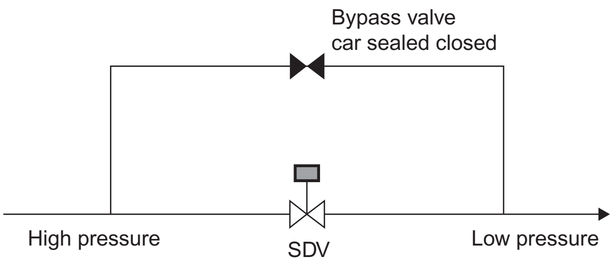

FIGURE 17.10

SDV bypass.

The danger with such a system is that someone may accidentally leave the bypass line open, thereby bypassing the safety safeguard created by the SDV. The normal operating procedure in such a case would be to either car seal or lock closed the bypass valve. Nevertheless, the possibility remains that it could be left open after restart, particularly if there have been a series of spurious trips and the operator has decided to leave the valve open until the situation is "finally sorted out." He may then forget to close or seal the valve, especially if he has had many other tasks to carry out at the same time.

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