39
Fire Prevention and Protection

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39.1
Introduction

In addressing fire prevention and protection problems, the fire and safety professional must apply fundamental principles of personal and professional integrity and act in terms of fundamental canons in fulfilling their duties. To do less is to fail in their duty to protect and serve people, the environment, or property under their stewardship.

Likewise, the professional must apply engineering and scientific knowledge to the problem at hand. Best practices have been developed and are available to professionals in the form of specifications, codes, standards, recommended practices, and guidelines. This chapter touches on some of those, but it is ultimately the duty of the professional to search out the latest vetted information on the specific subject in whatever form (academic textbook, professional society coursework, network of professionals, Internet) and apply it to the situation presented.

Finally, this chapter was written from the view of a professional identifying risk and applying risk mitigation techniques. Depending where the professional is practicing in the world, regulatory requirements may have different expectations. For example, US regulatory frameworks are generally based on compliance to specific, component-based aspect requirements whereas many other parts of the world rely on systematic performance-based approaches to meet a set of broad-based expectations. Thus, compliance requires a thorough review of the planned protection mitigations and, if there is uncertainty on what the regulations require, it is necessary to search out appropriate legal or regulatory consultation.

So how does one apply all this in practice?

39.2
Basic Principles

The professional should apply basic engineering and scientific principles to the task they have been asked to handle. For the purposes of this chapter,the basic principles are prevention first followed by protection (Brown, 2009).

Handbook of Loss Prevention Engineering, First Edition. Edited by J. M. Haight.

39.2.1 Prevention First

The concept is simple: eliminate the potential (likelihood) or eliminate the consequence and thus eliminate the risk. But how does one do this consistently?

Apply best practices and conduct quantitative or qualitative risk assessments, though keep in mind that it is not always possible or even prudent to eliminate all risk.

Consider legal and regulatory compliance. As noted above, it may not be practical to eliminate all risk. However, various agencies' regulatory requirements may appear to require elimination of risk. Legal and regulatory consultation is critical in assuring that risk is placed in perspective and compliance with regulatory requirements is achieved.

With this knowledge, one can consistently apply risk-based analysis and set appropriate levels of risk acceptance. Depending on the industry and the location of the activity, the design professional along with operational and legal staff can determine the level of acceptable risk. This acceptance should be based on a rigorous risk acceptance taking into account the potential hazards that the industry has along with the potential consequences of an event involving the hazard and the likelihood of that event occurring. For safety, operational, and legal reasons, it is important for the design professional and the operational team to look beyond their experience and the experience of the location in determining the hazard, consequence, or likelihood potential and consider both broad similar industry experience and related activity in another industry. For example, for a conveyor system in a mining operation one might want to look at similar activities in a sand and gravel or a heavy crude refining operation to understand the hazards, consequences, and likelihood involved.

39.2.2 Protection

Protection takes two forms:

- constructed protection facilities (including fixed detection, fixed automatic protection – sprinklers, water supplies)
- personnel-operated systems (fire brigades, fire departments, and their associated mechanical equipment).

Constructed protection facilities should be viewed as mitigating infrastructure and not a replacement for sound preventive measures. For example, life safety codes require minimum exit dimensions and those same codes require exits to be operational whenever people are inside a facility. Therefore, enhanced automatic detection and protection systems should not be considered as justification to allow exits to be blocked or locked.

Likewise, personnel-operated systems mitigate unplanned, unforeseeable events – the definition of a crisis. Fire, medical, and police departments require highly skilled and competent responders. For those events that are foreseeable in nature (wildfire, property protection, medical emergency, accident), responders have (or should have) clear, concise operating procedures. But what about the unforeseen, unplanned events (Bhopal chemical plant, India, 1984; Chernobyl nuclear plant, Ukraine, 1986; terrorist attack on United States, 2001), the crisis events?

When such an event occurs, best practice demands the responder to focus on a set of guiding principles.

The concept is simple: protecting people, the environment, or facilities places responders at risk. Therefore, it is important in planning protection to design in terms (guiding principles) that allow the responder the time to respond safely.

When a responder is faced with a crisis, the only operating manual may be the following guiding principle: always take the time to respond safely or not at all. A firefighter killed or seriously injured responding to an emergency does not serve anyone. Design protection with this in mind. Do not place the responder at undue risk in responding because they have to rush their response or take chances to accomplish their response goal – saving life, protecting life and property. Urgency must be balanced with focus on response, safety, and mitigation of the incident.

39.3 Design Basics

The following help the professional develop a design that supports the basic principles.

39.3.1 Design Development

This chapter is not intended to provide in-depth discussion about hazard identification, consequence and likelihood evaluation, risk assessment, or risk acceptance levels. The reader is encouraged to seek out detailed texts if they are new to the subject. However, a refresher of these tools is needed to set the basis for further discussion in this chapter.

Hazard identification requires the professional to list those hazards that are present. This should be done without regard for likelihood or consequence. For example, the hazards present in an oil storage tank farm may include the flammable or combustible nature of the oil products stored, electrical switchgear, walking surfaces on, near, or over tank bundwalls, and similar hazards.

Consequence evaluation looks at the worst-case scenario and the impacts of that worst case on people, the facilities or the environment. For example, the consequence of fire in the above-mentioned tank farm may be injury or fatality of one or more people, damage to the facilities resulting in lost revenue, and impacts on the environment.

Likelihood evaluation then either quantitatively or qualitatively assigns a numerical value to the potential for the consequence to occur. For example, the likelihood of a fire at a tank farm may be negligible if the product stored is limited in quantity, has a very high flash point, and is stored in accordance with god industry practice.

Risk is the product of the consequence and the likelihood of the hazard. Risk acceptance levels can be presented in many variations. Figure 39.1 shows a sample risk matrix with risk acceptance levels from acceptable to unacceptable. Based on the likelihood and potential consequence, the resultant risk (acceptable, further review, or unacceptable) is then used to assess the next steps either to eliminate or to mitigate the hazard first identified. For example, the risk based on the examples above may be acceptable. As such, the design professional would likely move on to the high-risk events.

When conducting risk assessments, the professional needs to be mindful of legal aspects and, if in doubt, seek legal advice to assure that all work done has proper legal protection, for example, attorney–client privileges for self-critical review.

With the risk assessment in hand, the professional can design the facilities in a manner that reduces or eliminates risk.

Once the design has been developed, the professional has likely published a set of design specifications, data sheets, and drawings that form the basis of a contract. It is for these documents that the professional may want to seek peer review, code compliance checks and conduct reviews to assure that risks have been properly addressed.

Again, the professional is encouraged to seek out greater detail, but the following are some examples of reviews that may be needed:

- **Peer review** – Have senior members of the design team or operations personnel review the basis of the design to assure that facilities will function as intended.
- **Compliance checks** – Enlist a knowledgeable code specialist to review the design for code compliance.

Sample risk matrix

Likelihood ↑			
High	Further review	Further review	Unacceptable
Typical	Acceptable	Further review	Further review
Low	Acceptable	Acceptable	Further review
Consequence →	Minor	Medium	High

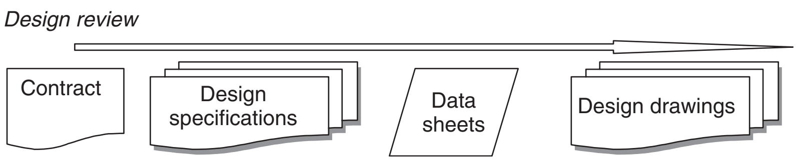

Figure 39.1 Sample risk matrix.

- **Reviews** – These may include process hazard analysis, fault tree analysis, and insurance risk analysis processes (Baybutt, 2012).

39.4 Practical Design Considerations

With the foregoing basis, the following provides practical guidance for the design professional in developing a facility. The considerations, guidance, and concepts assume a familiarity with underlying engineering principles.

39.4.1 Facility Layout and Construction Considerations for Fire Safety

When involved with facility layout and construction considerations, the safety professional has numerous codes and standards to begin their design considerations. Those codes and standards include:

- National Fire Protection Association
- American Petroleum Institute
- Uniform Building Code
- Uniform Fire Code
- Hospital and Hospice Care Guidelines.

Various publications also exist to which the practicing professional may wish to subscribe (these may be available online):

- *Building Safety Journal*
- *NFPA Journal*
- *NFPA Fire Protection Handbook*.

39.4.2 Layout Objectives

Protecting personnel and the public from exposure to spills, fires, explosions, heat, smoke, odors, hazardous releases, and noise is a matter of layout and spacing. When laying out a facility, consider present and future activities on adjacent property; open land may become a small community, civic area, or a hospital in future years. Consider future expansion of the facility and how it may impact or be impacted by design considerations today. For example, farmland/grassland, adjacent processing plants, and flammable construction should have a 20 ft perimeter fire break consisting of road, gravel, or similar non-combustible construction (NFPA 30; NFPA, 2012a). Will this provide adequate future emergency response capability or allow adequate set-back for future development?

Inside a facility, it is important to protect people and equipment. It is important to provide open space between process units as a buffer zone or to provide future space for facility maintenance and finally space to respond to an emergency. For example, during maintenance shutdowns or turnarounds, having space to stage equipment and allow access for both planned and emergency equipment is always appreciated by the operations. However, the additional space must consider the cost of property. In a high-value location, for example near a major metropolitan area, or in offshore locations, property is at a premium, so the professional needs to balance the cost and the benefit of space. Do not increase the risks by building new or expanding existing process units into those buffer zones.

39.4.3 Layout and Spacing

Layout and spacing support risk-based design through separation of fuel sources and ignition sources. It is an inherently safe method of design, providing for prevention and infrastructure protection. Therefore, it supports both good design practice and good emergency response practice. The factors to consider when laying out a facility and related equipment include the following:

- **Personnel and public safety** – Providing adequate space to operate and maintain facilities, to limit unnecessary or undesired public access, for example, schools, apartment complexes, or other highly populated areas.
- **Environmental** – Proximity to habitats, natural drainage routes (where does fire water run-off go?).
- **Economics** – Brownfields[1)] and greenfields[2)] development costs can be high; therefore, it is critical to evaluate carefully not only new spacing but also using buffer zones for installed equipment. It is also necessary to consider spacing impacts on offshore structures or other highly technical and congested facilities, including distilleries, electronics plants, and similar facilities.
- **Regulatory requirements** – Spacing from property lines and public or emergency easements may be regulated.
- **Process risks** – Plants handling highly volatile liquids or gases may require greater spacing than a low-pressure plant or a plant not handling hydrocarbons.
- **Emergency response capability** – Facilities lacking strong internal or municipal emergency response support should consider increased spacing and drainage control to minimize losses in the event of a fire.
- **Atypical hazardous facilities** – Unique facilities (new technology) should include vapor cloud and radiant heat modeling calculations to assess spacing needs or consider impacts from worse-case scenario events, such as an explosion.
- **Within structures** – Codes typically limit maximum allowable floor area between fire-rated separation walls, separations between floor levels, travel distances to exits, and separation distances between exits. From a design perspective, this is critical in locations where large groups of people can congregate (for example,

1) Brownfields is a term used to describe a redevelopment area, often associated with former industrial areas being redeveloped into mixed use, light industry, or commercial development. Typically, brownfields are located in central district areas and have limited expansion space.
2) Greenfields is a term used to describe a new development area. Typically greenfields are in areas without expansion restrictions, but often lack basic infrastructure.

night clubs or theaters) or uses of the structure limit easy of mobility through the structure (for example, high rack storage).
- **Within facilities** – Drainage and where outfall from fire water will be released.
- **Tall structures** – The World Trade Center attack demonstrated the need for designers to consider design and response capabilities of tall structures. Keep in mind that responders may need to use the same pathways for access that the occupants are using for egress. The Federal Emergency Management Administration commissioned a report that provides valuable information into the response of a structure under catastrophic conditions (FEMA, 2002).

Layout and spacing must be used in conjunction with other risk mitigation practices, including selection of materials of construction, fireproofing, and isolation of occupancy to provide a complete design.

39.4.4 Drainage Systems

The drainage system design must be considered when laying out process facilities. The drainage system can carry burning hydrocarbons or other flammable or combustible liquids close to adjacent property lines, evacuation routes, and critical equipment within the plant, thus exposing them to fire, heat, and smoke hazards. The designer should also consider the impact that these drains may have on the local environment. For example, consider how the drain will handle significant fire water flows and whether the drain will contain the volume. Will the receiving facility of the drain (for example, a sump, treatment facility, or lagoon) hold the expected maximum surge flow? If not, the responders need to be aware and mitigation plans need to address emergency response impacts.

39.4.5 Equipment Spacing, Fireproofing, and Electrical Classification

Equipment spacing is intended to:

- Minimize a vapor cloud from one piece of equipment from contacting a potential source of ignition.
- Reduce the potential for a fire on one piece of equipment from damaging adjacent equipment.
- Reduce the potential for a blast overpressure to be magnified and result in detonation.

An example of a spacing guideline is presented in Figure 39.2. Distances are based on fire hazardous zones and historical fire spread. Many engineering design companies maintain their own spacing guidelines. The safety professional should benchmark their spacing guidelines with others and balance economics and risk.

Fireproofing dimensions are intended to describe when a piece of equipment or structural steel is within a fire hazardous zone and should be fireproofed.

	Compressors	Intermediate hazard pumps	High hazard pumps	High hazard reactors	Intermediate hazard reactors	Moderate hazard reactors	Columns, accumulators, drums	Rundown tanks	Fired heaters, incinerators, oxidizers	Air cooled heat exchanger	Heat exchanger	Pipe racks	Units blocks valves	Analyzer rooms
Compressors	30													
Intermediate hazard pumps	30	5												
High hazard pumps	50	5	5											
High hazard reactors	50	10	15	25										
Intermediate hazard reactors	50	10	15	25	15									
Moderate hazard reactors	50	10	15	25	15	15								
Columns, accumulators, drums	50	10	15	50	25	25	15							
Rundown tanks	100	100	100	100	100	100	100	100						
Fired heaters, incinerators, oxidizers	50	50	50	50	50	50	50	100	25					
Air cooled heat exchanger	30	15	15	25	15	15	15	100	50	/				
Heat exchanger	30	10	15	25	15	10	10	100	50	15	5			
Pipe racks	30	10	15	25	15	10	10	100	50	/	10	/		
Units blocks valves	50	50	50	100	50	50	50	100	50	50	50	50	/	
Analyzer rooms	50	50	50	50	50	50	50	100	50	50	50	50	/	/

1 ft = 0.305 m
/ = no spacing requirements

Figure 39.2 Example of a generic plant spacing guide. Numbers are distances in feet.

Although these distances will often resemble the equipment spacing distances, they will not always be the same. The same guidance is available as described above.

Also, standards are available for calculating the thickness of fireproofing for a given structural member. These standards can be used to estimate the fireproofing needed or the loss prevention engineering professional can search out a number of manufacturers and installers of fireproofing on the Internet who can provide specific detail for the various fireproofing options as in Figure 39.3 (ASCE, 2007).

Electrical area classifications (NFPA, International Electrical Code, and API RP 500 (API, 2002)) contain distances describing potential areas in which a flammable vapor cloud or a combustible dust cloud may form. Fixed electrical equipment within these areas must meet the described electrical classification criteria. These distances do not address fire hazardous zones, hence they may differ from both the

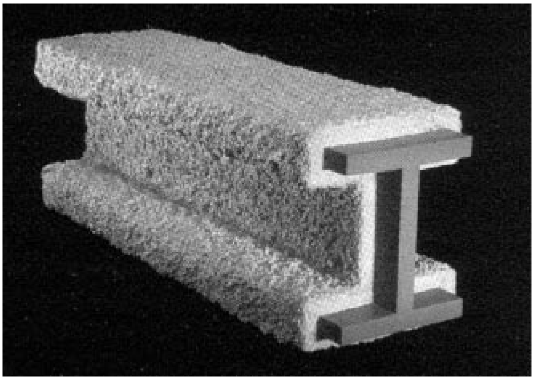

Figure 39.3 Cementitious fireproofing on a steel beam.

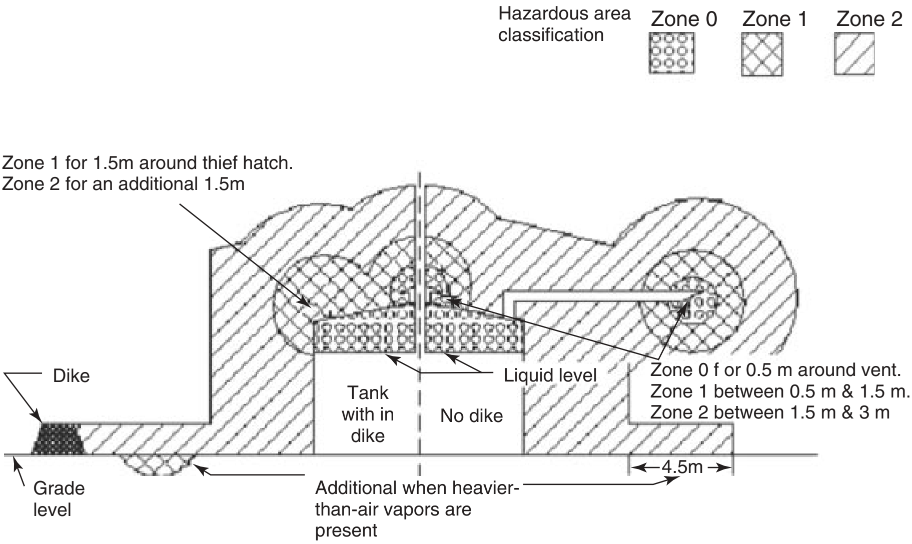

Figure 39.4 Electrical area classification (API, 2002).

fireproofing and equipment spacing distances presented above. The loss prevention engineer is recommended to obtain copies of these standards and review them in detail for their projects (NFPA 70; NFPA, 2011c). Figure 39.4 shows an example of a typical area classification for electrical equipment (API, 2002; IEC, 1995).

39.4.6 Design for Local Conditions

Local conditions need to be considered when laying out a new facilities or making modifications that may affect the safety of personnel and equipment. If historical records indicate a reasonable probability of extreme conditions, the designer

Table 39.1 Example of a qualitative benefit–cost analysis, for plant fire protection improvements.

Potential action	Benefits	Benefits: High = 3 Medium = 2 Low = 1	Costs	Costs: High = 3 Medium = 2 Low = 1	Benefits/ costs	Rank ratio
Remove one process unit to provide additional plant spacing	Reduced risks of explosion Improved maintenance access	3	High demolition expense Reduced operating capacity	3	1	3
Audit facility and determine what electrical equipment improvements are needed	Reduced risk of explosions from electrical equipment Reduce ongoing maintenance needs Improved motor efficiency Potential operating cost reductions	2	Moderate capital expenditures	2	1	2
Facility fire safety audit	Use risk ranking to identify improvement priorities	3	Audit prioritize capital budget	1	3	1

Source: present author.

should make appropriate provisions when laying out facilities. Extreme conditions include hurricanes, tornadoes, violent hailstorms, heavy snow loads, severe and prolonged freezing temperatures, airborne salt water spray, cooling tower fog, lightning storms, floods, tidal action, and exposure to earth slides, rock slides, or earthquakes. Also, in today's world, consideration of terror attacks or other acts of civil disobedience are necessary (DHS, 2011).

39.4.7 Protection of Critical Equipment

Critical equipment should be located and designed for maximum protection. For the purposes of this section, critical equipment is defined as that equipment necessary for safe, normal plant operation, and control as well as equipment necessary for safe shutdown during plant upsets, fires, and other emergencies. Critical equipment may include instrument air supplies, process control systems, electrical power, substations, main process block valves, certain pumps and compressors, emergency shutdown (ESD) and relief/depressuring systems, and fire water systems.

High-value equipment may warrant extra separation. A risk assessment with benefit–cost analysis should be conducted if the equipment has the potential to impact ongoing operations significantly (i.e., loss of equipment results in more than one month of business interruption or other similar measure of business interruption) (Table 39.1).

The example in Table 39.1 is a qualitative benefit–cost analysis. While the first two proposed actions result in equal qualitative benefit:cost ratio, the ranking is adjusted to recognize the high capital cost and reduced operating flexibility in the example. Simply reducing plant flexibility is not something most operating and planning staff will consider.

39.4.8
Protection for Utilities

Power-generating plants, boiler plants, and substations generally serve several process plants or facilities. They should remain operable when one or more of the process plants is in distress. It is prudent to have greater spacing between boiler plants and a high-pressure process plant than between two process plants. The reason is that a boiler plant draws significant air flow and is a source of ignition; therefore, greater spacing provides the protection of distance to reduce the risk of the boiler being the ignition source.

39.4.9
Plant Equipment Access

Equipment access and layout are also critical to safe normal operations, routine maintenance and shutdowns, and emergency response.

Spacing and access areas should be checked against the size and turning radii of various cranes and other equipment required for maintenance and shutdowns. In some situations, it is prudent to conduct a ‘‘dropped object study’’ to determine if the risk of a dropped piece of equipment is adequately mitigated by the layout and spacing. The concept of the study is to review qualitatively the lifting path that the load will take and ascertain, in the event of an incident the load is dropped, what impact it will have on the area in question.

39.4.10
Security

Plant location and degree of public access may indicate that plant borders and entrances should be supervised and protected with various passive – concrete barricades, planter boxes – and active systems – cameras or motion sensors. The Homeland Security web site (DHS, 2011) provides additional information with which both the designer and responder can learn about critical facilities security.

39.4.11
Evacuation

Evacuation routes should take into account the location of potential releases, prevailing winds, and drainage patterns. Best practice is to provide a minimum of two evacuation routes remote from each other. In the event of one route being blocked by an incident, then people and equipment can make use of the second route. Give consideration to the need for emergency equipment to enter the site and focus efforts on avoiding conflicts between those evacuating and those responding (*NFPA Handbook*; NFPA, 2008).

39.4.12
Block Layout 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 major elements. Streets that separate blocks are excellent fire breaks and facilitate movement and use of equipment.

Roads, pipeway and electrical overpasses, bridges, pipe tunnels, and curves must be capable of handling the largest equipment needed in the area: cranes, fire apparatus, drilling rigs, delivery trucks, and so on. Verify that roads and curves are adequately designed to allow adequate turning radii and load support for emergency vehicles. Assure that additional fencing does not limit access of equipment with overhangs during vehicle movement (turning). Remember that fire trucks are heavy and speed bumps should have approach and departure angles that limit the impact loads transferred between the vehicle and road surface as it passes over the speed bump.

For purposes of fire protection, economy of operations, and maintenance, main access roadways are needed. Within operating areas, every unit and facility should have roadways that allow for firefighting equipment. Within enclosed facilities, space consideration may lead the designer to reduce access pathways to minimum dimensions for lift trucks and small vehicles. When doing this, consider emergency access and the need to move people and equipment safely into and out of the area. Remember that it is not enough to gain access, there are times when the emergency equipment needs to exit the area quickly as conditions change. Do not create traps for firefighters or their equipment. Likewise, operational plans need to assure that emergency responders consider evacuation for their protection – remember that the best practice for responders is to leave themselves a way out.

During an emergency, it may be necessary to block certain roadways; therefore, each unit should have two or more approaches. Block layout will generally provide two-direction access. Likewise, consider facility access. Given security concerns, the desire may be to have limited and thus easily controlled access. However, provide two-direction, independent, all weather access. Remember that you may need to consider snow removal and ice conditions if the secondary access is not normally used.

39.4.13 Restricted and Unrestricted Roads

Motor vehicles may be ignition sources. To minimize the risk of a vehicle igniting flammable material in a facility, any road within 25 ft of potential release sources of flammable or toxic material is designated a restricted road. Restricted roads should not be used for routine plant travel of operations and maintenance vehicles (NFPA 30; NFPA, 2012a).

Traffic on restricted roads can be closely controlled by installing barriers and signs at the entrance to the facility, and by requiring procedures such as hot work permits for vehicles that must enter the facilities. This usually requires that the operators test for combustibles in the area prior to vehicular entry.

Unrestricted roads are those roads located more than 25 ft from release sources. They do not require traffic control.

39.4.14 Protection of the Public Through Spacing

Where practical, use offices, warehouses, and other low-risk buildings as buffers between the process plants and the public. Greenbelts and planted areas are often used to this end. These areas give the industrial facility a friendly, modern image that can make them more acceptable to the public (DHS, 2011).

39.4.15 Plant-to-Plant Spacing

The following are the major issues to consider in plant-to-plant spacing:

- **Personnel safety and operator access** – Operation, maintenance, and emergency response to a facility are all enhanced when adequate space is provided to allow people to do their job without feeling cramped or enclosed.
- **Explosion damage prevention** – Economics dictate land be utilized efficiently; however, consider the impacts of an explosion causing damage to other surrounding facilities and possibly furthering damage and resultant loss of production.
- **Spill spread control** – Effective spacing can allow spill control to be channeled more effectively.
- **Vapor releases and vapor cloud travel** – Spacing allows vapors to disperse before reaching other potential ignition sources.
- **Fire and fire spread** – As with explosion potential, fires can and have been known to spread across open areas and ignite other facilities.
- **Flood control** – Spacing can allow for better flood control if the facility is in a flood-prone area.

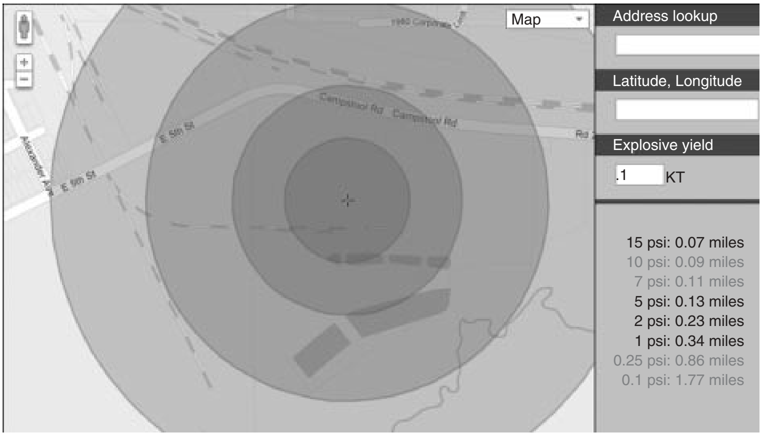

Figure 39.5 Impact zone radius (Van Den Bosch, 2005).

- **Maintenance access** – If equipment has to be pulled, spacing can make the job easy, and reduce production down time.
- **Firefighter access** – Reducing conflict between those evacuating and those entering a site is enhanced by greater spacing.
- **Radiant heat from fire** – Radiant heat from a fire varies as the square of the distance; increasing the distance reduces the heat flux, and thus the potential for other combustibles becoming secondary fires (Van Den Bosch, 2005).
- **Economical construction** – Land prices in most locales are at a premium. Balancing the costs for more land and the risks of closer spacing is a role of the designer. Qualitative and quantitative methods are available to help the designer propose alternatives to the owner. Some methods available include quantitative analysis of blast overpressure and determining what the maximum overpressure is that a process may generate. Then, through use of isopleths, the designer can show that the overpressure structures may be exposed in a credible scenario. Structural engineers can then detail structures that can withstand those forces and provide guidance on impact on people. An example using HYDEsim is presented in Figure 39.5 (Van Den Bosch, 2005). Typical design parameters for facilities range from 1 to 5 psi. In this example, facilities would need to be designed for blast overpressure up to 0.25 mile (400 m) from the epicenter.

39.4.16
Temporary Buildings

Temporary buildings should always be of concern for the loss prevention engineering professional. They are often overlooked and defeat the concept of minimizing the employee population around process plants or other hazardous locations. API 752, 2010 does not underestimate the impact that a temporary office can have at a sewage treatment plant where digesters create methane gas or at small LPG storage facilities. Right-to-know laws and local emergency response committees (LERCs)

Figure 39.6 Oil and gas facility (Brown, 2012).

are beginning to recognize these locations as at-risk locations for terrorist or other subversive activity. Therefore, temporary buildings should abide by the following guidance whenever they are located adjacent to hazardous (chemical, biological, or physical) facilities. For further information on this topic, refer to the Environmental Protection Agency (EPA) Chemical Emergency Preparedness and Prevention Office (CEPPO) web site, *http://www.epa.gov/osweroe1/content/epcra/index.htm*.

Owing to their mobile design, temporary buildings can be less resistant to damage from a fire or vapor cloud explosion. Blast overpressure or toxic release scenarios usually represent the most stringent spacing criteria for temporary buildings. Electrical components within a temporary building may also provide a source of ignition to a flammable vapor cloud.

Temporary buildings and trailers should not block access and evacuation or egress routes and vehicle traffic patterns should be evaluated during temporary building siting – does the temporary building introduce increased private vehicle traffic or result in additional deliveries to the inner areas of the process plant (a security concern)? Temporary buildings and trailers should not be located where personnel frequently have to or will choose to traverse through high-hazard areas in order to access the structures. The addition of temporary buildings may require the installation of barricades and/or barrier tape to minimize the likelihood of increased employee population in high-risk areas of the facility. 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.

Given recent high-profile incidents in which fatalities have occurred, many jurisdictions are now looking at strengthening the regulations controlling temporary buildings. The designer can again rely on best-practice principles – prevention first. Locate the temporary building out of the plant environment. This may mean a longer walk or drive, but the trade-off is having people away from the risk and, in the event of an incident, people can stay in their work location to help support the response rather than evacuating the site (Figure 39.6).

39.5 Oil and Gas Facilities

With modern techniques, pad drilling of oil and gas wells and related facilities has allowed resource development in urban and suburban settings. It has also introduced additional perceived risk due to proximity to local communities, services (such as hospitals, schools, and emergency responders), and other commercial activities.

When developing a well site and related facilities, the loss prevention engineer needs to consider the following:

- Proximity to homes, schools, and services. What impacts would the community experience if there were a fire or release at the facility? Also, be aware that not all wells flow with positive pressure; many require mechanical means to produce the resource. As a result, additional power transformers, fuel storage, and other equipment may be present that require design considerations.
- The nature of the well product – is it gas, is it oil, does it contain hazardous compounds such as hydrogen sulfide? Is there adequate water pressure in the area to protect exposure should a fire occur?
- Access in an emergency: are there preferably two points of access remote from each other? Prevailing winds and commercial or residential activities may limit access; consider how responders can access the site. Also consider how local communities can be notified in the event of an emergency. In more developed regions, local emergency services may be able to mass telephone the local community.
- Are there storage tanks on-site? Will the product be trucked or sent out by pipeline? While pipeline is often the preferred method to limit risk, mechanical integrity programs, pipeline location services, and other issues need to be considered.
- Is there public access to the site? Is it possible for people to access the site? If so, consider risk of vandalism, injury, or fire. Although fencing can resolve many of these issues, there are areas where landowners may not allow fencing. For example, regulators of public lands may not allow fencing as it impedes cattle and sheep grazing or wildlife natural pathways. Private land owners may limit fencing for the same reasons.

39.6 Natural Gas Vehicle Fueling Stations

With the increased interest in natural gas vehicles (NGVs), ranging from personal automobiles to long-haul freight tractors, it is possible that the loss prevention engineering professional will be faced with designs for an NGV fueling station. Some considerations of fire safe design and operation are presented here.

- Consider the basics for good prevention; limit the amount of natural gas that can escape from the facility in the event a connection within the facility fails.
- Pressures of 3600 psi are typical for fueling NGVs. Hence fire departments are likely to be concerned about high-pressure gas connections being made and broken on a regular basis by the public. Breakaway connections, instructions for proper filling, and safety shutdown systems are all aspects of good design. Also, NGV fueling stations for long-haul freight or local delivery heavy-duty fleets may require both high-pressure and high-volume gas supplies. Again, fire departments will be concerned about safety systems in place to limit the amount of natural gas that can escape should a connection fail.
- Consideration may be given to fire detection systems or loss of back-pressure systems. In the case where these systems are considered, the professional should first understand what other inherent safe designs have been incorporated into the design to reduce risk.
- Consideration should be given to physical protection of the fuel onboarding facilities and the vehicle during fuel onboarding. Considerations include:
  - barricades around fueling islands
  - containment for vessels
  - temperature compensation for fueling lines.

The above are in addition to standard fire protection precautions for any fueling station.

NFPA 52, *Guidelines for Compressed Natural Gas Vehicular Fuel Systems Code*, provides additional information for the design and installation of an NGV facility (NFPA, 2010).

39.7 Hazard Versus Risk

Codes and regulations may require certain levels of component-based versus performance-based compliance. The term component-based means that the code or regulation requires a certain aspect be done in a certain way, while performance-based does not rely on the specific aspect but rather the overall performance. In simple terms, component-based tells the professional, for example, how many doors of a certain rating are required, whereas performance-based tells the professional the expectations of the overall system to protect life safety in a building.

Although component-based is relatively easy to design and operate based on a set of specific aspects, it is slow to adopt innovative approaches that would potentially eliminate the need for specific aspects.

In another respect, component-based codes and regulations factor in the consequence and likelihood analysis and assume an acceptable risk level if the operator is in compliance. However, the regulatory and hence operational risk is what happens when technology allows numerous ways to mitigate the fire risk?

Recent guidance from the US Occupational Safety and Health Administration (OSHA) has addressed this question by focusing on the hazard analysis and publishing guidance that suggests if the hazard of flash fire is a potential, then personal safety requires the use of certain personal protective equipment (PPE) (fire-resistive clothing) (OSHA, 2011). Although on initial review of this guidance it seems to make sense, actually it fails to meet the basic principles of prevention first followed by protection. It also fails to meet the principles of risk that consider both the consequence and likelihood of the event. In the case of any PPE, the standard of prudent operation should be based on industrial and occupational hygiene practices of engineering control first, procedural control second, and then any remaining risk mitigated through proper PPE selection. Component-based codes and regulations, if they use hazard as the test to determine a requirement, fail in protecting people. Generally, the better approach from a loss prevention professional perspective is to look at the risk and apply performance-based standards of operation. However, the professional is reminded that each jurisdiction has different rationales for their regulations. If the professional is unsure, they should seek legal and regulatory consultation prior to implementing their designs or operational programs.

In summary, hazard and risk are not synonymous terms. The professional is encouraged to be clear which aspect they are dealing with and apply their professional judgment accordingly.

39.8
Practical Operations Considerations

With a focus on cost control, operating staff are challenged to find ways to reduce compliance costs. In this section, the focus is on ways in which the professional can support the operation in reducing costs without a reduction in fire safety performance (Pinheiro, Cranor, and Anderson, 2011).

The same considerations of hazard identification, consequence and likelihood analysis, and risk assessment apply. The professional needs to assess the risk. Again, reviewing the earlier part of this chapter is important for a common understanding of terms. Often Operations will use the terms ‘‘hazard’’ and ‘‘risk’’ interchangeably. They are not interchangeable terms, and need to be treated separately. As a refresher, hazards are the conditions that may lead to undesirable events. Risk is the resultant function of the likelihood of the hazard being present and the consequence of the event involving the hazard.

Whether Operations are investigating an incident, starting a new facility, or maintaining status quo in the operation, they should consider risk and prioritize their operating plans based on risk. Again, however, in some regions of the world, legal and regulatory realities require actions that may not be justified based on risk assessment. In those cases, one of which is described below, legal counsel should be sought and considered. Keep in mind that strict conformity to code requirements may make the operation unprofitable. Although profitability alone is not the measure for taking prudent action, it must be considered if the business is to remain viable. Likewise, the reader is reminded that codes are usually developed to apply to typical, broad classifications of facilities and the professional needs to consider this when advising Operations on what is possible to accomplish versus what the code may or may not address.

39.9 Floating Roof Tank Operation Considerations

Floating roof tanks provide many aspects with regard to good fire safe design and operation.

Floating roof tanks are generally used to store flammable liquids (see Figure 39.7). In a floating roof tank, the roof literally ‘‘floats’’ on top of the stored liquid. The space between the roof and the shell has a mechanical shoe that presses against the shell to assure that the roof remains centralized in the tank. Various seals are used to cover the narrow annular space between the roof and the shell, hence there is very little vapor space. The relative lack of vapor space means that the potential (likelihood) of a fire (consequence) in flammable liquid storage (hazard) is greatly reduced; however, some basic operational considerations need to be covered, including the following:

- Maintain the roof to shell seals. If the seal is not properly maintained, vapors can be released to explosive levels, if not human health hazard levels or environmental emission limit levels.
- Maintain deck legs in proper position. Legs are provided in most designs to allow for efficient maintenance. When the tank needs to be taken out of service for maintenance, the legs are extended so that the roof will rest at a given height, allowing workers to enter underneath. By design, the roof floats on the product. If the legs are not in their proper operating position, and this needs to be determined and agreed with operations, there is a risk the legs will ‘‘land,’’ allowing the roof to rest above the product level and thus create a hazard through the creation of a vapor space. Likewise, when the product level returns to the level where it can float the roof, history points to instances where the roof did not float and in fact sank. Again, this presents the hazard of product on the roof, rather than below.
- Maintain fire suppression systems. History indicates that tanks over about 300 ft in diameter (nominal 100 m) are difficult if not impossible to extinguish if they become fully engulfed (Riecher, 2008). Likewise, history indicates that with a properly operating fire suppression system focused on the area where fire is likely to occur, the annular area of the seal has a high probability of being extinguished. Hence maintaining fire suppression systems is critical. Typical suppression systems use firefighting foam agents. These agents are usually water-based, hence corrosion of the delivery system is a consideration that the designer and operator of the system need to be aware of and plan accordingly (NFPA 12A;

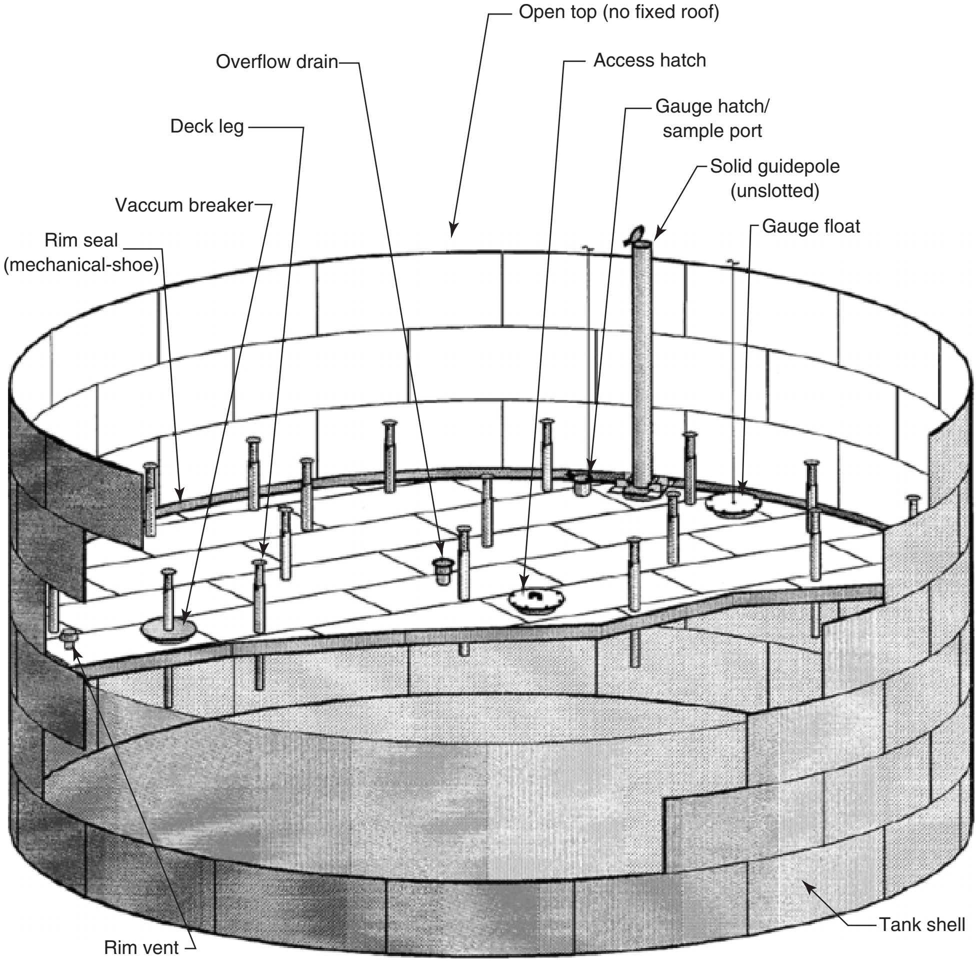

Figure 39.7 Typical floating roof tank (Wikipedia, 2011c).

NFPA, 2009). Often operations will seek to avoid testing of the system to reduce costs and concern over corrosion; however, the professional should encourage and support periodic system testing which includes flowing to the foam maker outlet ports. Without periodic tests, it is at best difficult to assure that the system will perform when needed. Also, cold weather needs to be considered when conducting tests or designing the system. Generally, the flows required do not result in the need to heat trace or otherwise acclimatize the firefighting foam delivery system downstream of the supply valve. However, upstream of the valve standard winterization methods should be followed (NFPA 12A; NFPA, 2009).

39.10 Investigating and Reporting on Fire Losses

39.10.1 Overview

The author has witnessed and investigated many hydrocarbon-based fires including a 300 ft (100 m) diameter floating roof tank fully engaged fire. The information presented below is based on personal experience of investigating numerous incidents and generating fact-based, reliable, relevant recommendations. This section discusses the general procedure for investigating a fire and preparing the fire report (Figure 39.8). Also, an example root cause analysis is included at the end of this section. As the reader will learn, the process described here could be used for any incident or accident investigation.

When a fire occurs, it is important to learn why it happened in order to prevent similar fires in the future. In all but the most obvious, lowest risk, and least potential cases, investigation is warranted.

39.10.2 Data Collection

It is important to set aside a few hours to concentrate at the fire scene. The following are some recommended basic steps on which the investigator should concentrate as the evidence often leads to the primary cause of the fire:

1) Begin the investigation as soon as the fire area is safe to enter, and before any cleanup or repair work is started. Use a camera or video recorder to record the scene. However, be certain to engage legal representation to assure appropriate use of the pictures and video. Generally, avoid photographing people involved in the incident out of respect. If video recording is used, it is generally recommended by legal counsel to do so without audio. Any description of what was filmed can be added later if used in testimony.

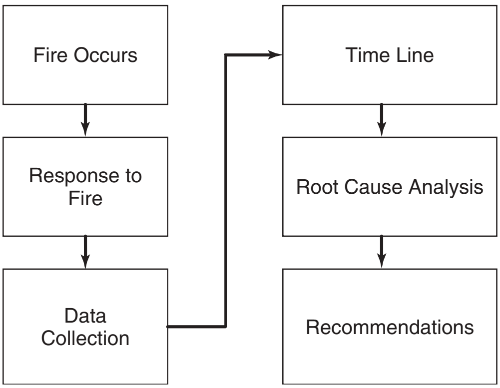

Figure 39.8 Sample fire investigation flow chart (Brown, 2009).

2) Obtain eyewitness reports before people leave the area. Interview operators on shift, firefighters, and any other eyewitnesses. Try to get as much detail as possible, including sequence of events, estimates of elapsed time, color of fire and smoke, noise and smells. Consider tape-recording your discussions with eyewitnesses. Have the witnesses review their remarks and edit accordingly. Also, be aware that memories and impressions of what witnesses saw or heard can be misleading. Use witness statements and your own investigation techniques to understand the facts.
3) Review records and logs. Immediately following a serious fire, it is recommended that all logs and records be dated, time marked, and retained for later reference. Other useful records include material samples, inspection records, drawings, weather records, and any information that could help to reconstruct conditions and events leading up to the fire. Some computer systems overwrite data every 24 h. Check for video from security cameras in the area and do not discount the video even if the camera is pointed away from the area in question.
4) Inspect in detail the physical evidence and the damage. If a fire has burned in a confined area, sketch a plot plan to show the outer limits of the damage, and where flame actually touched.
   Flame contact with any object heats the object rapidly to 1000 °F or above. If flame has not reached an object, its temperature will seldom exceed 400 °F. Table 39.2 provides guidance for estimating fire temperatures in an area during a fire. Use this guidance to draw "temperature circles" on the plot plan.

Table 39.2 Material response to temperature (Cote, 2003).

Material	Characteristics	Temperature (°F)
Poly(vinyl chloride) (PVC)	Distorts	185
Polystyrene	Distorts	210
Paint	Scorches	250
Plastic	Melts	250
Plastic	Chars	250–400
Paint	Chars	250–400
Nylon	Distorts	300–360
Wood	Ignites	380–510
Dry coke	Formed	400–1000
Steel	Strength lost	1000–1200
Silver solder	Melts	1165–1450
Aluminum	Melts	1220
Glass	Softens	1400–1600
Brass	Melts	1600
Steel	Excessive scaling and grain coarsening	1600
Concrete	Spalling	1800–2000
Copper	Melts	1980
Stainless steel	Melts	2600

Insulation fibers, grass, and leaves will be singed and charred by ignition of a vapor cloud. These clues can help define the extent of the vapor cloud prior to ignition.

The source of the fuel is usually located near the center of the highest temperature circle. An unexpected cool zone inside the otherwise hottest area might point to a fuel source that continued to flow throughout the fire, providing localized cooling. This could be the initial leak or failure.

Photographs for permanent record can be helpful during the review stage of investigation. Search out witnesses with cell phones who may have video recorded the event.

5) Identify the fuel source. After sketching the "circles of temperature," look carefully at the area inside the hottest circle to identify damage or leaks that occurred during the fire. Rule out these items as an initial source of fuel. For example, piping that splits during a fire will have knife-thin edges along the tear. These thin edges were created by the flame, which weakened the steel enough for it to bulge, become thin, and then tear. On the other hand, failed piping that shows no thinning at the edge of the failure except for possible corrosion should be noted as a potential initiating event if not an initial cause. A sample of the suspected fuel is helpful if you need to determine its vapor pressure or flash point to support your conclusions from the examination of the fire site.

   In many facilities where air pollution control devices are required, flame arrestors are installed to provide a level of protection between the combustion source of the control device and the source of the emission, typically a low-pressure vessel or tank. History indicates that these flame arrestors, while providing protection, can be the point where a protective barrier has failed with often the result being a tank roof separated from the shell and Operations wondering what happened. As the investigator, one needs to look at protective barriers such as flame arrestors and not assume that they performed as designed. Flame arrestors rely on very narrow passages to cool the gases passing through the arrestor element to a point below its ignition point. If the element is damaged, or not properly installed, even a gap of an additional $^1/_{16}$ in (8 mm) is enough to allow the flame front to pass and result in the tank roof being separated from the shell (CSB, 2007).

6) Identify the ignition source. After you have determined the probable source and type of fuel, inspect the fire area again and review eyewitness reports to try to identify the source of ignition. Common sources of ignition are as follows:
   a. welding, cutting, drilling, or burning
   b. open flame, such as that from fired boilers or heaters
   c. oil-soaked insulation on piping above 350°F
   d. hot bearings on pumps
   e. engines, both stationary and portable, or vehicles
   f. pyrophoric compounds
   g. spontaneous ignition; look for instances of thermite reactions if aluminum is involved

h. static electricity; look for dangling chains, wires, or other conductors that provide a spark gap
i. electrical sparks or arc.

Do not be intimidated by what looks like total destruction, an impossible mess, or a shapeless pile of junk. Look past the rubble. Visualize the original conditions. Search out detailed clues. Identify the pattern of temperature and flame contact, and you will have surrounded the fuel source.

7) Document details of the emergency response to the fire, including:
   a. use of detection, alarm, shutdown systems
   b. effectiveness of pre-fire plan
   c. number of firefighters, including mutual aid, and response time
   d. amount and type of firefighting equipment used
   e. level of effectiveness of firefighting equipment and tactics, including fixed equipment, mobile equipment, and the facility firewater system.

For large fires, it is helpful to map locations of fire trucks, monitors, hose lays, and the outline of the fire area.

39.10.3
Investigation Team

Employee participation in the investigation team is critical (Cote, 2003). Operation, maintenance, or contractor personnel directly involved with the incident, including the first-line supervisor, should be included in the investigation team. As needed, include team members with expertise in process, materials, machinery, or instrumentation. A team leader with investigation experience can facilitate the group effort.

Supervisory and management personnel need to understand that their presence in the investigation team can sometimes cause intimidation and limit the team's effectiveness.

39.10.4
Time Line

The first step in analyzing the data collected is to establish a detailed time line of events leading up to the fire, especially any changes in plant operations over the few days prior to the event. The investigation team determines the approximate time of fuel release, ignition, and discovery of the fire. Subsequent equipment failures that added fuel to the fire, operator response to the incident, and firefighter response should be documented on the time line until control and extinction are achieved.

39.10.5
Root Cause Analysis

Root cause analysis is a method used to identify the underlying causes of an incident. Using root cause analysis, the investigation team tries to answer questions such as the following:

- What was the source of ignition and why was it in proximity to a source of fuel?
- Why did the fire progress beyond the incipient stage?
- What systems affected the size of the incident (positive/negative)?

Each incident includes both physical causes (e.g., power surge) and human causes (e.g., inappropriate maintenance or operator response). Management system causes often allow the human causes to occur (e.g., inadequate training or procedures). Root cause analysis is a method to identify each type of cause and to help prevent recurrence of the incident. The ''root'' causes of an incident are the most basic causes that can reasonably be identified and that we have control to fix. There are numerous commercial products in the marketplace and an Internet search can identify various vendors. These products typically build on the root cause analysis techniques and provide the end user with formatted templates, instruction, and proprietary solutions. For more general information on root cause analysis, the reader is recommended to review the Wikipedia web site related to five why technique and root cause analysis (Wikipedia, 2011b and Wikipedia 2011c). Although this is not a peer-reviewed site, it offers general information that can be helpful in understanding the common aspects of root cause analysis.

Other definitions of causes are:

- **Physical causes** – When equipment or devices fail or change, or physical conditions have some effect that leads to undesired consequences. Some examples are piping broke/leaked, pump was vibrating, temperature indicator failed, furnace tubes developed coking, tank was struck by lightning, or electrical circuit was shorted out.
- **Human or behavioral causes** – A human action or lack of action that caused the undesirable physical condition or action. Examples are did not open the valve, did not perform inspections for corrosion, lighted the furnace without sufficient purging, read the gauge incorrectly, used the wrong design code, or skipped a step in the shutdown procedure. These may or may not be human error, because sometimes the human may be following a procedure that is not correct or may not have been properly trained or instructed to carry out that activity.
  Behavioral-based actions have been an area receiving additional scrutiny in the past decade. The reader is directed to additional information provided in the literature (Geller, 2000).
- **System causes** – A procedure or management system that did not support the human in taking the right actions. It may be absent, not enforced, incorrect, or otherwise not usable. Usually these are synonymous with root causes.

Effective incident investigation systems look beyond human/behavior causes to determine root causes in the management systems. In this sense, a management system is the mix of equipment, procedures, training, and culture that supports people in doing their jobs.

As an example of the three types of basic causes, consider an incident where a pump bearing failed (Table 39.3). Additional subject matter may be found in the incident investigation chapters of this book (Chapters 35–37).

Table 39.3 Generic basic cause analysis.

Cause	Basic types of causes	Fix
The bearing overheated	Physical	Replace the bearing
The operator did not oil the bearing	Human/behavior	Tell the operator to keep the bearing oiled
There was no requirement for oiling the bearing	Management system	Modify a procedure to require oiling bearings

Source: present author.

39.11 Fire Reporting

39.11.1 Importance

Reports of fire are of great importance in a fire protection program. They provide the following information:

- Reasons for fire occurrences, in order that corrective measures can be taken.
- At governmental and commercial levels fire loss experience has been accumulated over many years. This experience serves as a basis for changes in the way we design facilities, expenditures for fire prevention and firefighting equipment, underwriting insurance, and training.
- Valuable data for discussions with regulatory bodies regarding legislation affecting industrial and commercial operations.
- A source of material for fire training programs.

39.11.1.1 What Fires Should Be Reported?

All fires should be reported and documented. Fires are defined as any occurrence of fire, combustion explosion, or spread of fire involving properties, products, operations, or employees, not intentionally ignited for a useful purpose, irrespective of resulting deaths, injuries, or damages.

39.11.2 Definitions

39.11.2.1 Reportable Fire

All fires, regardless of size, dollar loss, or injury, should be reported.

Every fire provides a lesson in fire prevention and every report broadens our knowledge of fire protection techniques. That is why it is important to report all fires, regardless of loss. Two objectives of a report are to describe the effectiveness of fire control measures and to reveal the circumstances that permit a fire to start in unexpected places or in an unexpected manner. The test is: ''Was the fire an expected result or was it part of the work being done?'' Even if this fire was small, it may reveal a situation that, under slightly different circumstances, could result in a serious loss. This type of information, combined with experience in other areas, can provide the basis for important steps in a fire protection program.

39.11.2.2 **Recordable Fire**

In order to standardize across industry, it is important that the fire reporting program used has a recordability statistic defined. Often low-value, low-risk potential fires are reported but not recorded. A fire reporting program should define the loss levels to record fires. Insurers, government agencies, and other may define these limits, but if not, consider damage loss value, loss potential, and loss product value as guidance for recording. The important thing is to report the fires, identify the root causes and track so that actions to reverse negative trends in fire loss can be addressed.

39.11.3
Preparation of a Report

Following the investigation, a report is prepared. A sample report form is given. Note that all questions apply to every fire, and answers to some questions may need more space than is given on the form.

It is important that the information be accurate and complete, and that statements based on opinion rather than fact be so designated. Reports cannot contain too many facts.

Sketches and/or photographs showing the area affected by fire and indicating significant dimensions or distances are desirable.

In the legal system, it is adversarial and at times appears in conflict with the no-blame culture needed to investigate and explain a fire effectively to improve the fire prevention program.

Therefore, it is important to try to prepare fire reports in such a way that possible legal concerns are not compromised. The following points give some guidance:

- Report only the facts; avoid opinions.
- Avoid words such as detailed, full, or complete. If a final report falls short of that goal, use of such words could be difficult to explain.
- Assume that whatever is written is public information.
- If the possibility of legal action exists, you may wish to seek legal counsel to review the report. Attorney–client privilege concerns can be discussed and are outside the scope of this chapter. Suffice it to say that if you believe that the fire may lead to litigation, consult an attorney with experience in your industry handling such investigations.

However, do not let the possibility of legal action deter you from investigating and documenting the fire investigation. Legal reasons, and in today's environment Homeland Security reasons, may prevent you from sharing all details, but share and communicate what you can. Sharing what you have learned with others is a best practice.

39.11.4 Report Form

The front of the report form asks for specific information on the fire being reported; that is, where it was, what was involved, what was damaged, who was injured, when it happened, and when it was controlled and extinguished. The section titled Event Sequence includes a time line to help you organize the description of the incident. Mark the time line in chronological order starting with the first important event and ending with the date and time that the root cause analysis (if performed) was started. Describe what happened, including:

- The events leading up to the fire. The most valuable lessons from incidents often come from a thorough and objective examination of the events leading up to a fire.
- The discovery of the fire and initial response. What happened to either increase or limit losses between the time the fire was discovered and the time it was controlled? Were fuel sources isolated? Was an ESD system used? Was anyone hurt at the start of the incident or during firefighting?
- Control and extinguishing of the fire. Describe the procedures used to fight the fire. Who responded – the fire brigade?; the municipal fire department? Were firefighting tactics effective, and what were they? How long did it take to extinguish the fire? Was there anything unusual about the control methods that should be passed on to others in developing or improving their fire protection programs?

Root cause analysis of the fire provides information that is important to the investigation and a most useful tool for gaining experience to prevent future similar fires. In a typical fire report, the following sections may be found:

39.11.4.1 Sources of Fuel and Oxygen

Indicate the source of fuel (*Example*: tank, pump, piping). Air is the usual source of oxygen. However, check the box marked ‘‘other’’ if there was another oxygen source (*Example*: hydrogen peroxide, leak). Describe what happened to allow the fuel to mix with oxygen (*Example*: tank was overfilled, pump seal failed, tank inerting system failed).

39.11.4.2 Source of Ignition

Explain why the source of ignition was in proximity to the flammable mixture. Why did the fire start?

- **Example 1**: A lighting strike in the vicinity of the Buffalo Wallow tank setting caused vapors from the pressure/vacuum vent to ignite. It is thought that the pressure pallet inside the vent valve stuck in the open position.

- **Example 2**: A pump bearing failure caused internal friction (heating) and vibration that led to failure of the mechanical seal. A release of flammable material occurred when the mechanical seal failed. The release was ignited by hot pump surfaces.

What facility systems contributed to the severity of the fire, or reduced its impact? Several choices are provided. Check all those responsible for allowing a small, easy-to-control fire to escalate into a large fire, or those that effectively limited losses or the extent of the fire. This information is helpful because:

- it can be used to increase the effectiveness of your fire prevention program
- it may be useful at other locations similar to yours.

Explain how the system checked above affected the fire (e.g., how they failed to limit losses, or why they were successful in reducing fire losses).

Elaborate on the advantages or shortcomings of the systems that affected fire losses. Feel free to add marginal notes or attach a second sheet. *Example*: equipment could not be isolated from fuel sources because brass block valves melted.

What incident prevention (process safety management (PSM)) systems could have predicted the fire, or prevented it from occurring? Check all the PSM systems that were in place, but were not used or were needed to reduce risk of fire.

Is action necessary to prevent recurrence? List any proposed actions (or attach root cause analysis and lessons learned). When developing recommendations review the identified root causes and ask yourself the following questions:

Should existing facility or PSM systems or other management controls be modified to:

- prevent a flammable mixture from forming?
- eliminate ignition sources?
- reduce the impact of a fire?
- improve emergency response?

39.11.5 How to Estimate Loss

In most cases, the reported loss includes the cost of in-kind replacement of the damaged structure or equipment, including removal and clean-up of damaged equipment and the value of the product or material consumed in the fire. It does not include losses associated with future production unless the insurance coverage includes such clauses. Report the replacement cost or value of any non-facilities (i.e., third-party) losses. If the damaged equipment is abandoned, report the book value. The loss reported should be that resulting from the fire or explosion; do not include the value of substantial improvements made when the structure or equipment is replaced.

Only losses resulting from fire should be reported as a fire loss.

39.12
Example Root Cause Analysis Report of Fire

See Figures 39.9 and 39.10.

39.13
Fire Suppression Equipment

This section addresses protection systems, including water suppression systems, dry chemical extinguishers, and special application systems.

39.13.1
Single Fire Concept

The selection of a fire extinguishing system for a facility is designed to handle firefighting efforts associated with one major fire at a time. The design capacity of major firefighting facilities is determined by the largest single fire contingency (Brown, 2009).

However, some system components are sized to handle less significant contingencies. For instance, foam concentrate requirements for special hazard systems are usually determined by a single largest tank fire with protected exposures rather than by the worst contingency, which may be a fire in the process area.

39.13.2
Fire Fighting Methods

Whether the reader is a proponent of the fire triangle or the fire tetrahedron, either can be used to visualize the methods to extinguish a fire:

- quenching (cooling)
- smothering (blanketing)
- flame suppression (heat absorption)
- flame propagation interruption (free radical-chain breaking).

39.13.2.1 Use of Water as an Extinguishing Agent

Water continues to be the most widely used and accepted fire-extinguishing material because it is economical and effective. Used properly, it has excellent quenching capabilities, cooling effectiveness, and, for some materials, vapor dispersion characteristics. A gallon of water applied at 50 °F and entirely vaporized into steam at 212°F removes over 9000 BTU of heat. For a general understanding of latent heat of vaporization and a comparison between water and another common fire-extinguishing agent, carbon dioxide, see Wikipedia (2011a).

In a light spray, water cools the surface of combustible or flammable liquids and combustible materials such as paper or cardboard. It may form froth on viscous oils, which can further cool the fuel to below its flash point, resulting in

Root Cause analysis report

Company	XZY Supply
Address	123 C Street
City	Centerville
Telephone	123-9876
Contact	Joe Jackson
Date	January 1, 2007

Event	Fire/medical/motor vehicle (select one)
Event description	Two firefighters were burned when room fire flashed over.
Facility type	Building electrical closet
Equipment type	Electrical
Responders	Engine company #54

Details of event

At 2 am on January 1, 2001, firefighters responded to an alarm from XYZ Supply. The source of the alarm was quickly identified as a fire in the electrical closet of the building. Firefighters responded to the room and prepared to enter knowing flash over was a potential risk. Power to the facility was cut and after some difficulty due to blocked access ways, fire hoses and portable fire fighting equipment was brought to fight the fire.

Upon entering the room, the fire did flash over and the fire fighters (2) sustained minor injuries. Injuries where classified as 1st degree burns to wrists and neck of both fire fighters. They were provided first aid treatment by paramedics at the site and returned to their normal duties.

The fire was extinguished and an investigation into the event was begun. Fire marshal working with building owner to ascertain cause.

Response

1. Alarm received at engine company #54 at 1:53 am, January 1, 2007
2. Engine Co responded to scene at 2 a.m.
3. Claxon siren sounding and smoke observed through windows.
4. Automatic alarm panel identified location as electrical closet
5. Two hose lines and two portable CO_2 extinguishers routed to closet
6. Access blocked entrance to building slowing progress initially.

Event Sequence

1. 3 pm, December 31 employee locks facility and leaves vehicle parked as directed at building entrance
2. 1:48 am January 1, the fire detection system indicates smoke in the electrical closet
3. 1:49 am cross zone detection goes into alarm.
4. 1:50 am claxon siren sounds
5. 1:50 am central supervisory system (BED Security and Safety) receives alarm.
6. 1:51 am operator notifies building owner that the alarm has sounded.
7. 1:53 am operator calls 911 and reports fire
8. 1:53 Engine Co #54 responds
9. 2:00 am Engine Co arrives scene
10. 2:02 am Engine Co identifies source of alarm – electrical closet
11. 2:04 am Engine Co hampered by access
12. 2:06 am power cut to building
13. 2:08 am two fire fighters access room, open door
14. 2:08 am fire flashes over (as expected), fire fighters receive minor burns
15. 2:10 am fire brought under control using one hose stream.
16. 2:15 am fire extinguished
17. 2:20 am fire fighters receive first aid treatment for 1st degree burns
18. 2:30 am building owner arrives
19. 3:15 Engine Co returns to station

Figure 39.9 Generic report. (Source: present author.)

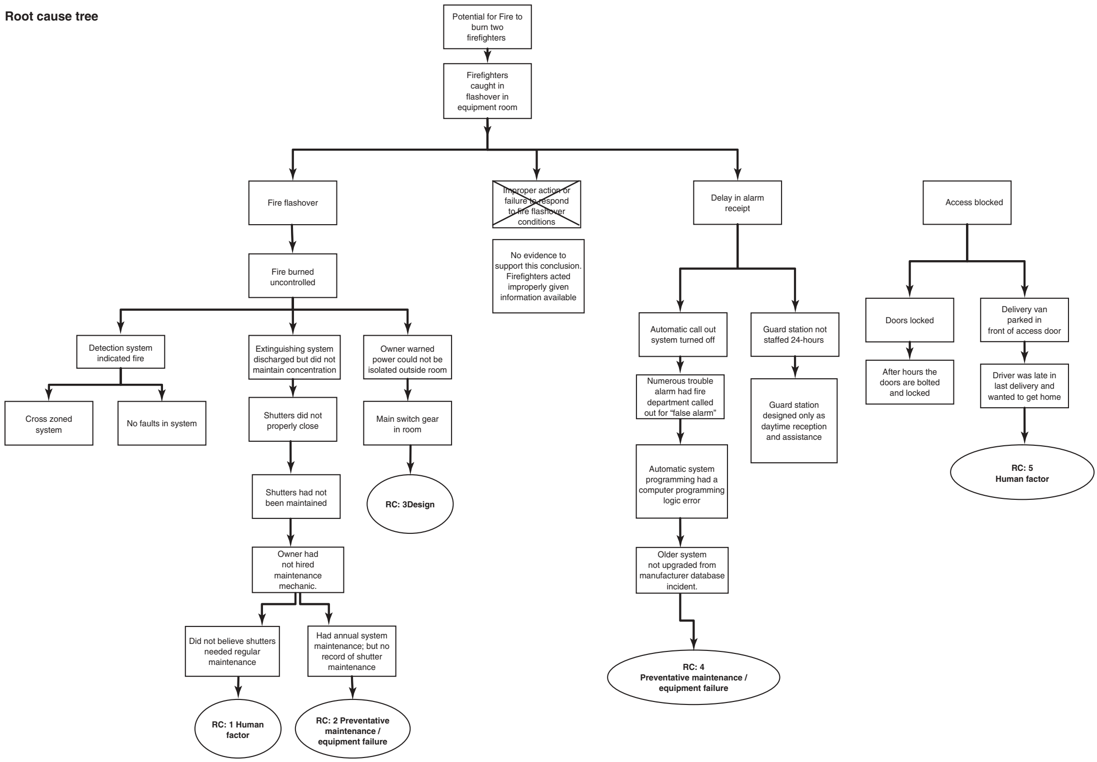

Figure 39.10 Generic root cause analysis report. (Source: present author.)

Root Cause	Description
1. Human factor	Believed fire dampers did not need routine maintenance
2. Preventive maintenance / equipment failure	No maintenance conducted on fire dampers as recommended by vendor
3. Design	No internal power cut off
4. Preventive maintenance / equipment failure	No update of computer software, update available
5. Human factor	Access blocked as driver in hurry to return home

Recommendations	Person responsible	Date due

Attachments	
Photographs	
Witness statements	
Maintenance records	
Medical reports	
Procedures	
Job safety analysis	

Prepared By: Josephine Profess

Figure 39.10 (*continued*)

''extinguishment by frothing'' – a special case of quenching. A water spray is also a flame suppressor. It reduces the size and intensity of the flame. Water cools and protects materials exposed to flames, both products and structures. Even as a spray, however, water is not usually capable of extinguishing fire of gases or vapors of volatile oils.

Water can also be used as a smothering agent, particularly in fighting fires involving liquids heavier than water (e.g., carbon disulfide).

The steam generated as fire vaporizes water can displace or exclude air, extinguishing the fire by smothering. Smothering is aided by confining the steam generated to the combustion zone.

Flammable materials that are soluble or miscible in water (e.g., methanol) may, in some instances, be extinguished by dilution. However, attempting this on a large-scale fire may result in flooding or further spread of the fire if effective containment is not provided.

39.13.2.2 **Layout and Size**

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. Pipelines should be routed to minimize fire or mechanical damage. In cold climates, distribution lines should be buried below the frost line. Recommended depth of cover in feet for firewater systems in the United States is given in Figure A-8-1.1 of (NFPA 24, 2010).

When possible, firewater mains should be arranged in loops around process facilities and industrial or commercial facilities. Shutoff valves should be located to allow isolation of system segments for maintenance or in case of line failures 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 the design pressure for that area.

A 4 in minimum firewater header should be provided in each facility area to serve incipient stage hose stations. Branch lines to hose stations should be 2 in minimum. Firewater mains and headers looping the facilities should not be less than 8 in in diameter. Laterals supplying single hydrants or monitors should not be less than 6 in in diameter. In fire water systems using salt water or non-potable sources, the pipe diameter should be increased by one size to allow for deposits and scale buildup, or lined or plastic materials should be considered.

39.13.2.3 **Best Practice Considerations for Sprinkler Systems**

The following provides some considerations that the designer may need in order to determine which type of system to use.

1) **Wet pipe water sprinkler** – Use in locations where combustible materials of construction or occupancy warrant the need for rapid response for small, pre-flashover potential fires to occur. Typical examples are hotel rooms, hospitals, retail occupancy, and even computer centers. Often designers are concerned about the potential for water to damage electronic equipment. However, the standard of reliability of wet pipe systems combined with the

pragmatic view that if the room is involved in fire, the sooner an extinguishing agent is applied the less total damage occurs, results in the designer recognizing that a wet pipe system can be effective in many occupancies.

2) **Dry pipe sprinkler system** – Use in locations where a freeze potential exists or the nature of the occupancy can tolerate no water exposure potential unless the area is involved in an active fire.
3) **Deluge system** – Use where massive water flows are needed to provide additional cooling to limit the potential for greater damage. An example is a deluge system on liquefied petroleum gas (LPG) storage tanks at a bulk storage facility.
4) **Pre-action systems** – Consider a pre-action system in conjunction with either a dry pipe or deluge system. A pre-action dry pipe system may be used in a warehouse environment where a freeze potential exists, but in the event of incipient stage fire detection the system would be charged with water, and should an individual sprinkler head activate the protected area would have immediate protection. In the case of a deluge system, the pre-action would be part of the automatic response – although this is seldom needed in staffed facilities, unstaffed facilities may warrant the pre-action system to begin water flow at the incipient stage detection of fire.

39.13.2.4 **Fire Extinguisher and Equipment Inspection and Maintenance**

39.13.2.4.1 General

All fire extinguishers (see Figure 39.11) should be inspected at least monthly or at more frequent intervals where conditions warrant, and they shall be given a more detailed maintenance servicing annually, or whenever the monthly inspection indicates a need. This is a regulatory requirement in most areas where the company operates.

Table 39.4 overviews the minimum inspections that should be made.

Figure 39.11 Dry chemical fire extinguisher (Ansul, 2012).

Table 39.4 Generic inspection report.

List of extinguisher inspections	Water			Dry chemical units			
	Stored pressure	Pump tank	Carbon dioxide	Halon 1211	Disposable shell	Cartridge operated	Stored pressure
1. Ensure extinguisher is in designated place, clearly visible, and accessible	×	×	×	×	×	×	×
2. Ensure visual seal(s) are intact	×	×	×	×	×	×	×
3. Check pressure indicator or gauge	×	×	×[a]	×	×		
4. Take from bracket, heft for proper weight	×	×[b]	×	×	×	×	
5. Examine for damage, corrosion, and so on	×	×	×	×	×	×	×
6. Check nameplate and instructions for legibility	×	×	×	×	×	×	×
7. Examine hose for cuts, weather cracks, and so on	×	×	×	×	×	×	
8. Check nozzle and hose for plugging and operation	×	×	×	×	×	×	×
9. Check mounting bracket	×	×	×	×	×	×	×
10. Return extinguisher to proper location	×	×	×	×	×	×	×
11. Record inspection on tag and Check Sheet	×	×	×	×	×	×	×
12. Initial and date monthly inspection check sheet	×	×	×	×	×	×	×

[a] If equipped with pressure indicator.
[b] CO_2 extinguishers should be weighed every 6 months.
Source: present author.

39.13.2.4.2 Inspection

The inspection is a ‘‘quick check’’ to ensure that an extinguisher is in its designated place, is accessible, has not been actuated or tampered with, and that there is no obvious physical damage, corrosion, or condition to prevent operation. The frequency of inspections will vary based on the needs of the situation; they should normally be conducted at regular intervals not to exceed 1 month. Inspections should be completed by facility operators (as opposed to outside contractors). This will familiarize operators with the location and operation of extinguishers. The value of an inspection lies in the frequency, regularity, and thoroughness with which it is conducted. The inspector should include inspection items appropriate for the type of extinguisher in use (see Table 39.4).

In locations where caking of the powder in cartridge-operated dry chemical extinguishers has not proven to be a problem, opening the extinguisher to dump and screen the powder at monthly inspections is not recommended. This procedure itself can cause caking by allowing moisture to enter.

39.13.2.4.3 Maintenance

The maintenance check is a ''thorough check'' of the extinguisher and is performed annually. Its purpose is to give maximum assurance that an extinguisher will operate effectively and safely. A complete maintenance check should also be performed whenever the need is indicated by the monthly inspection.

Maintenance checks should be performed in accordance with the instructions on the manufacturer's label and the requirements of NFPA 10, Portable Fire Extinguishers. The following are some specific comments on the maintenance of selected types of extinguishers.

For dry chemical extinguishers maintenance needs to considering:

- placement near vibrating equipment, including vehicles (as powder may settle and cake in extinguisher,
- high air flow areas (as powder may not be delivered to fire if high air velocity), and
- damp locations (as corrosion may be higher)

For inerting agents (CO_2, Nitrogen) consider:

- Confirm tags and signage address suffocation risk.

For water- based agents:

- Confirm storage locations are freeze protected.

39.13.2.5 Explosion Suppression

Suppression of explosions is possible under certain conditions, because a short but significant period of time elapses before destructive pressures develop. If conditions are right, it is possible to use the time available to operate a suppression system.

Effective use of the rate of pressure rise to suppress an explosion requires three major considerations in the design of suppression systems:

1) The explosion must be detected in its incipient stage to allow time for operation of the suppression equipment. Owing to the relatively short time available, detection and suppression must be automatic, with provisions to discriminate between an explosion and ambient variables that normally exist.
2) The mechanism for dispersing the extinguishing agent must operate at extremely high speed to fill the enclosure completely within milliseconds after detection of the explosion. The detection must automatically actuate to assure no time lag. The extinguishing agent must be dispersed in a very fine mist form at rapid speed, normally through the use of an explosive release mechanism.

3) The extinguishing agent is normally a liquid compatible with the combustion process to be encountered. Factors involved in the suppression mechanism are the same as those for fire extinguishing – cooling, inerting, blanketing, and combustion inhibiting.

Explosion suppression systems are not in general use in the petroleum industry, but they may be considered for the protection of high-hazard, high-value operations where an explosion would have very serious consequences and normal methods of fire protection are not adequate. Explosion suppression systems are more commonly encountered in dust handling processes and airplane maintenance facilities. NFPA 69, 2008 ''Explosion Prevention Systems,'' provides further information on this subject.

39.14 Roles and Responsibilities

To conclude, it is important that the loss prevention professional help define, support, and encourage the following roles and responsibilities in an organization they support.

39.14.1 Managerial

The manager's role is to oversee implementation of the strategy for fire prevention and protection in an organization.

Training for the manager is related to communicating and auditing performance of the staff and operations they manage.

For the manager, training programs that stress communication both internally and externally are critical.

39.14.2 Supervisory

The supervisor's role is to implement and organize their staff to accomplish their specific roles within the function (whether it is operations, maintenance, emergency response, or staff).

Training for supervisors is focused on plans and procedures to complete the actions needed. Additionally, training should focus on development in areas of communication and feedback on performance. The goal of the training should be to assure all employees, contractors, or visitors the expectations for fire safety are clearly articulated and understood by all.

39.14.2.1 Employees

The employees' role is basic – they are or should be expected to follow the plans, procedures, and rules related to their job function.

Training should be focused on the skills needed to perform their job safely and to identify and communicate to other employees or supervisors when the work may create or be exposed to a hazard.

39.15 Conclusion

As stated in the Introduction, the responsibility of the loss prevention engineer is to be guided by the principle of prevention first followed by protection. This chapter has presented the reader with a broad overview of these principles through the design process, including concepts of risk-based design through proper spacing, design considerations, and material selection. It has provided an overview of the fire investigation process to help understand better the events that show that, even with sound design, incidents occur that require protection. It ends with a discussion of the common types of suppression, including the prevalent use of water, either through automatic systems or through hand-held extinguishers.

The subject of fire protection is constantly evolving and new technologies challenge the loss prevention engineer both to find solutions and to provide solutions. The loss prevention professional is encouraged when dealing with this subject to identify sources of information through codes and standards, texts on the fundamentals of fire, and in networking with other loss prevention professionals.

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